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Technology Assessment of Carver-Greenfield Municipal Sludge Drying Process

WWI Consulting Engineers, Emeryville, CA

Prepared for

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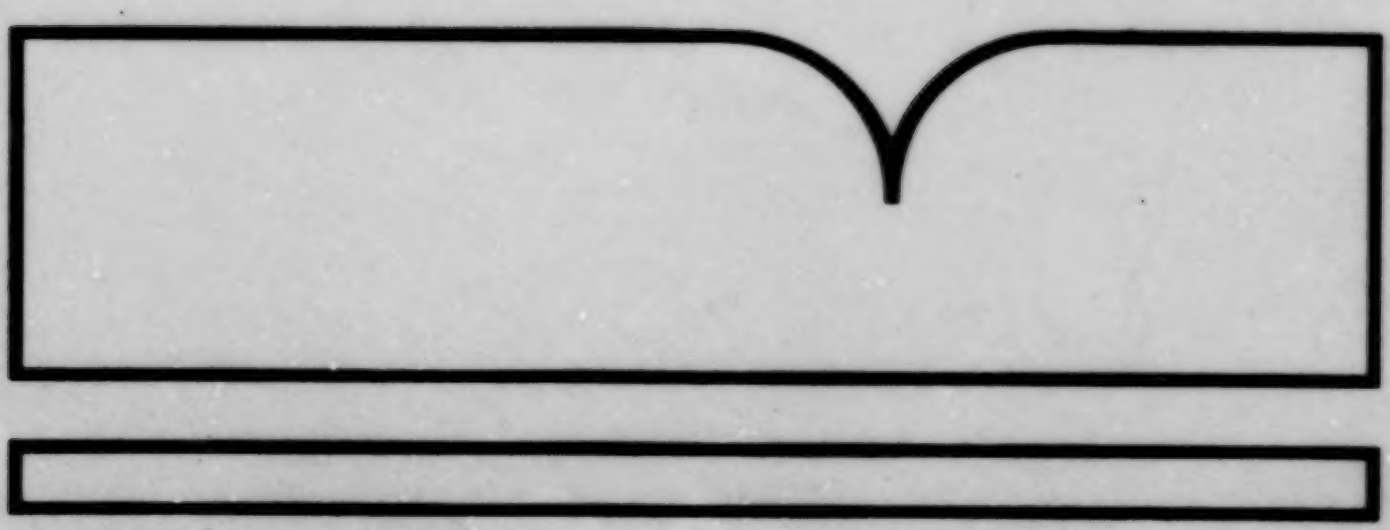

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December 1984

TECHNOLOGY ASSESSMENT OF

CARVER-GREENFIELD

MUNICIPAL SLUDGE DRYING PROCESS

by

Henry C. Hyde, P.E.
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EPA Contract No. 68-03-3016

Project Officer

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16. ABSTRACT

This project provided a technology assessment of a promising alternative for drying municipal wastewater sludge. Evaluated was the Carver-Greenfield (C-G) process which uses the principle of multiple effect evaporation. The process can dry aqueous solutions or slurries with a wide range of solids content (4-45%). The unique characteristic of the process is the addition of a carrier oil which maintains viscosities at a low enough level to facilitate pumping and heat transfer when the solids content becomes higher as water is evaporated. The process has been used primarily in the food, pharmaceutical, and industrial wastewater treatment industries and has seen limited application for municipal sludge drying. The only municipal application in this country is now under construction for the City of Los Angeles Hyperion Energy Recovery System (HERS) project. The process appears energy and cost effective. On the other hand, it is a proprietary process with an associated licensing fee, and it is technically complex compared to most other municipal treatment processes. The process does, however, deserve consideration as an alternative sludge drying process.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provides the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

The innovative and alternative technology provisions of the Clean Water Act of 1977 (PL 95-217) provide financial incentives to communities that use wastewater treatment alternatives to reduce costs or energy consumption over conventional systems. Some of these technologies have been only recently developed and are not in widespread use in the United States. In an effort to increase awareness of the potential benefits of such alternatives and to encourage their implementation where applicable, the Water Engineering Research Laboratory has initiated this series of Emerging Technology Assessment reports. This document discusses the applicability and technical and economic feasibility of using the Carver-Greenfield municipal sludge drying process for municipal wastewater treatment facilities.

Francis T. Mayo, Director
Water Engineering Research Laboratory

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ABSTRACT

The objective of this report is to evaluate the technical and economic feasibilty of using the Carver-Greenfield municipal sludge drying process for municipal wastewater treatment facilities. This process uses the principle of multi-effect evaporation and is primarily employed in the food, pharmaceutical, and industrial wastewater treatment industries. The process can dry aqueous solutions or slurries with a wide range of solids contents (4 to 45 percent). Fluidizing oil is added to the aqueous slurry before the sludge is introduced into the first evaporator. The oil maintains the viscosity at a level that will allow continuous pumping and also facilitate heat transfer in the later-stage evaporators where the solids contents are higher as a result of water evaporation. The fluidizing oil is recovered after drying by mechanical de-oiling steps such as centrifugation, filter pressing, or hydroextraction (steam stripping). The result is a dry product with 90 percent or greater solids content.

The C-G process is patented by Dehydrotech Corporation (formerly Carver-Greenfield Corporation) and is marketed under exclusive license arrangements by the Foster Wheeler Energy Corporation. The patented process equipment and appurtenant hardware can be negotiated directly with Dehydrotech.

Associated patent issues may create complications with federal funding that can cause delay in project implementation. In addition, use of the process requires a negotiated license fee. For the City of Los Angeles Hyperion Energy Recovery System (HERS) project, the license fee was approximately $1.4 million or about 8 percent of the equipment capital cost.

Currently, no comparable sludge drying processes are available. Thermal sludge drying or conditioning processes (e.g. flash drying, wet-oxidation) are based on different thermodynamic principals and are not analagous to the multi-effect evaporation system. Indirect contact steam dryers are the closest conventional technology to the C-G process.

The C-G drying process appears to be a cost-effective, energy efficient method applicable to the wastewater industry. Research and development for application to municipal wastewater solids drying has reached the point for full-scale imple-

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mentation. The City of Los Angeles HERS project will be the first full-scale municipal wastewater solids facility in the United States using the C-G process when it is placed into operation in 1985. Trenton, New Jersey is currently under design and Chicago, Illinois is seriously considering the process. Full scale facilities using the C-G process for municipal sludge drying are operating in Japan.

Based on this assessment, the following recommendations are made regarding identified needs to continue to develop this technology for the municipal wastewater industry:

- Municipal wastewater agencies should consider the C-G process on a site specific basis due to the variable process configurations, energy and environmental considerations, and cost.

- Pilot testing of the C-G process is necessary to develop specific design criteria to guide full-scale projects.

- The construction cost and operating characteristics of the C-G facilities for the City of Los Angeles and City of Trenton should be tracked to compare design objectives with performance characteristics and cost.

- There is a need to disseminate technical and cost information on specific C-G projects (e.g. Los Angeles, Trenton) addressing the following areas of concern:

  - Municipal wastewater residual solids dewatering/drying performance.

  - Construction and operating cost.

  - Patent status of light oil technology.

This report was submitted in fulfillment of Contract No. 68-03-3016 by WWI Consulting Engineers under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 1981 to August 1983, and work was completed as of August 1983.

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SECTION 1

TECHNOLOGY DESCRIPTION

INTRODUCTION

The Carver-Greenfield (C-G) drying process uses the principle of multi-effect evaporation and is primarily employed in the food, pharmaceutical and wastewater treatment industries. This study was conducted to evaluate the technical and economic feasibility of using the process for municipal wastewater treatment facilities.

The C-G process is patented by Dehydrotech Corporation (formerly Carver-Greenfield Corporation), and it can dry aqueous solutions or slurries with a wide range of solids content (4 to 45 percent). Fluidizing oil is added to the slurry before the sludge is introduced into the first evaporator. The oil maintains the viscosity at a level that will allow continuous pumping and also facilitates heat transfer in the later stage evaporators where the solids contents are higher as a result of water evaporation. The fluidizing oil is recovered after drying by mechanical deoiling steps such as centrifugation, filter pressing or hydroextraction (steam stripping). The result is a dry product with 90 percent or greater solids content.

A flow diagram describing how the process fits into a total sludge management system is shown in Figure 1. Sludge to be processed is first thickened or dewatered to reduce the amount of water to be evaporated. Thickened sludge is then mixed with an oil (carrying medium) such as No. 2 fuel oil or Isopar L (an Exxon product) at a suggested ratio of 1 part dry solids to 5 to 10 parts oil. By use of an oil, fluidity is maintained in all effects of the evaporation cycle, and formation of scale or corrosion of the heat exchangers is minimized. The sludge-oil slurry is then pumped to the multi-effect evaporator where water is vaporized. The remaining solids-oil mixture is subsequently centrifuged to separate the oil and solids. The oil is recycled and reused, and the dry solids are discharged for further processing or disposal.

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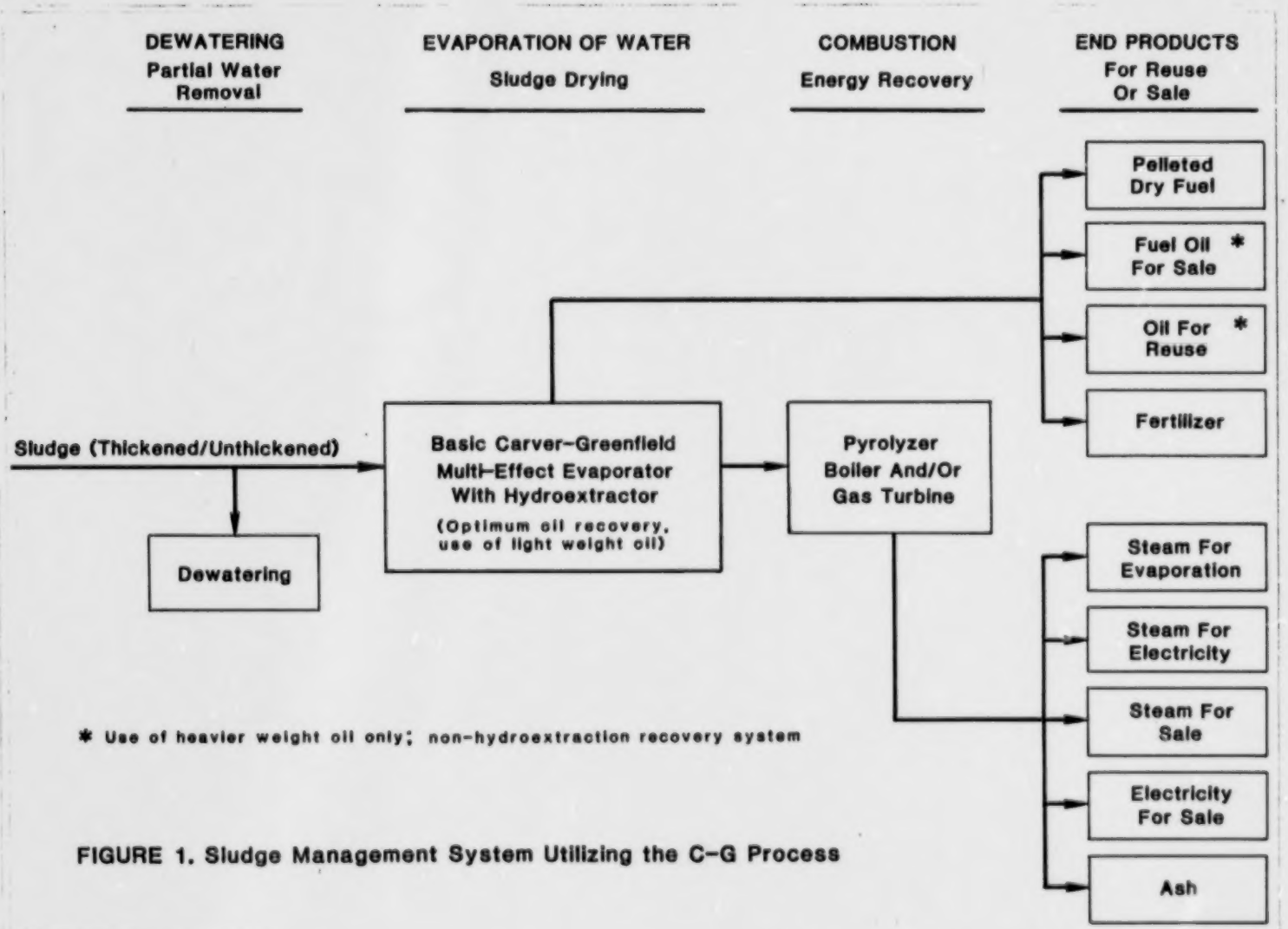

FIGURE 1. Sludge Management System Utilizing the C-G Process

Multi-effect evaporation affords an economy of scale over single-effect operations through the reuse of heat. The C-G process employs reverse flow, multi-effect evaporation with steam being added to the first effect. In a three-effect system, vapor from the first effect is used to heat the solution in the second effect, and the vapor from the second furnishes heat to the first. Vapor from the last effect is removed, condensed, and discharged. Through the reuse of heat in the multiple-effect process, the amount of water removed per pound of steam supplied increases with increasing number of effects.

In order to understand the thermodynamic principles of mulitiple effect evaporation and the chemical engineering terminology used in this report, the reader is referred to standard texts (e.g. L. McCabe and C. Smith, Unit Operations of Chemical Engineering, 3rd Edition, McGraw-Hill, 1976).

In its simplest theoretical form, a single-effect evaporator can evaporate a maximum of one kilogram of water per kilogram of steam supplied, and a double-effect evaporator will evaporate two kilograms of water per kilogram of steam supplied, etc., because of the reuse of heat. Depending on the number of effects used, the amount of kilojoules (Btu's) required per kilogram (pound) of water removed will vary. For a single-effect unit, about 2300 kilojoules per kilogram (1000 Btu's per pound) of water removed is required and for a double-effect unit, 1150 kilojoules per kilogram (500 Btu's per pound) of water removed, etc. A vacuum is applied to the various effects so as to reduce the vaporization temperature requirement necessary to vaporize the liquid, and to maintain a positive temperature difference within each effect so that heat can be transferred. Conventional heat drying processes normally require 3450 to 4600 kilojoules per kilogram (1500 to 2000 Btu's per pound) of water removed. Therefore, in comparison, the C-G process is an energy efficient sludge drying process.

It would appear that an infinite economy of scale would result from the use of an infinite number of effects. Several factors, however, limit the number of effects practicable in a system. Each effect of a multiple-effect evaporator operates only on a fraction of the total temperature drop across the system. The total drop is seldom larger than that employed in single-effect evaporation and the capacity per unit area of heating surface is reduced proportionately. Thus, a savings in fuel requirements may be realized through multiple-effect operation but equipment costs will be greater. Currently a system being designed by the City of Los Angeles will use four effects. In most cases no more than three or four effects are

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economical, but the actual number is largely influenced by prevailing fuel costs.

Most proposals on treating municipal sludge with the C-G process include a combustion reactor to recover the heat value of the dried product. Theoretically, this is an attractive combination of processes since water can be evaporated with multiple-effect efficiency prior to combustion or gasification. Fuel gases produced during pyrolysis or waste heat from an incinerator can then be used to supply the energy requirements of the Carver-Greenfield process. The dried product may also be marketed as a soil conditioner.

Currently, there are no comparable sludge drying processes available or being developed. Thermal sludge drying or conditioning processes (e.g. flash drying, wet-oxidation) are based on different thermodynamic principles and are not analagous to the multi-effect evaporation system. A solvent extraction drying process called the Basic Extractive Sludge Treatment (B.E.S.T.) process was tested by Resources Conservation Co. but development was discontinued in 1979 due to technical and economic problems. Therefore, the Carver-Greenfield dehydration process is a unique sludge drying technology.

The Carver-Greenfield process is proprietary requiring a license fee or royalty. In addition, portions of the process are patented. Patent issues create complications with federal funding for construction projects that may cause significant delay of project implementation.

BRIEF HISTORY

The initial concept for the C-G process occurred in 1949 during attempts to dry waste emulsions for the recovery of vitamin oil. Basically, the process is a technique utilizing the principle of evaporation and involved adding oil to replace water. Initially, the process concentrated in the food industry in the 1950's. The developmental work was performed under the direction of Charles C. Greenfield while employed by Fred S. Carver, Incorporated.

In 1964, the C-G process was introducted to the wastewater treatment field in Hershey, Pennsylvania at the Hershey Corporation. The facility employed three evaporation stages and ran successfully for ten years. The Hershey facility represented a milestone for the C-G technology since hydroextraction was demonstrated on a full-scale basis for the first time.

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SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The C-G solids dewatering/drying process appears to be a cost-effective, energy-efficient method applicable to the wastewater industry.

Research and development for application in the wastewater industry has reached the point for full-scale implementation. The City of Los Angeles Hyperion Energy Recovery System project will be the first full-scale municipal wastewater solids facility in the United States using the C-G process when placed into operation. Trenton, New Jersey is currently under design and Chicago, Illinois is seriously considering the process.

Based on this assessment, the following recommendations are made regarding identified needs to fully develop this technology for the municipal wastewater industry:

- Municipal wastewater agencies should consider the C-G process on a site specific basis due to the variable process configurations, energy and environmental considerations, and cost.

- Pilot testing of the C-G process is necessary to develop specific design criteria to guide full-scale projects.

- The construction cost and operating characteristics of the full scale C-G facilities for the City of Los Angeles and City of Trenton should be tracked. Full scale construction cost and operating information is a key need at this time to determine the widespread viability of the process.

- There is a need to disseminate technical and cost information on specific C-G projects in the following areas of concern:

  - Municipal wastewater residual solids dewatering and drying performance.

  - Construction and operating cost.

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SECTION 3

DETAILED TECHNOLOGY DESCRIPTION

As illustrated in Figure 2, in the C-G process the sludge is fluidized in the fluidizing tank by the addition of oil. Oil is fed in metered amounts typically ranging between 5 and 10 parts of oil per part of dry sludge solids by weight. The oil-sludge mixture is then processed through a grinder and fed to a surge tank. From the surge tank the mixture is pumped to the first stage evaporator. The number of evaporators for a particular installation will depend upon specific design criteria. Regardless of the number of stages, however, approximately equal quantities of water are evaporated in each stage and each evaporator would be of identical design.

Elements of the process and equipment that may be utilized are discussed below (Reference 1).

EVAPORATORS

The evaporators used are of the conventional falling film type and function in the following manner:

- Sludge-oil mixture is pumped to the dome of the heat exchanger or "tube nest" and falls through vertical tubes as a film on the tube interior. Heat is transferred from either process steam or hot vapor to the sludge in the shell of the heat exchanger. The temperature of the film within the tube increases. The flow of sludge and steam or hot vapor is counter current from stage to stage.

- When the mixture enters the vapor chamber a portion of the moisture is driven off as a hot vapor and serves as the evaporative medium in the preceding evaporative stage. The only difference between the operation of any of the stages or effects is that process steam serves as the evaporative medium in the first effect while hot vapor is used in all other effects. Hot vapor condensate from the shell side (outside of the tubes) of the evaporator is collected and drained to a hot well.

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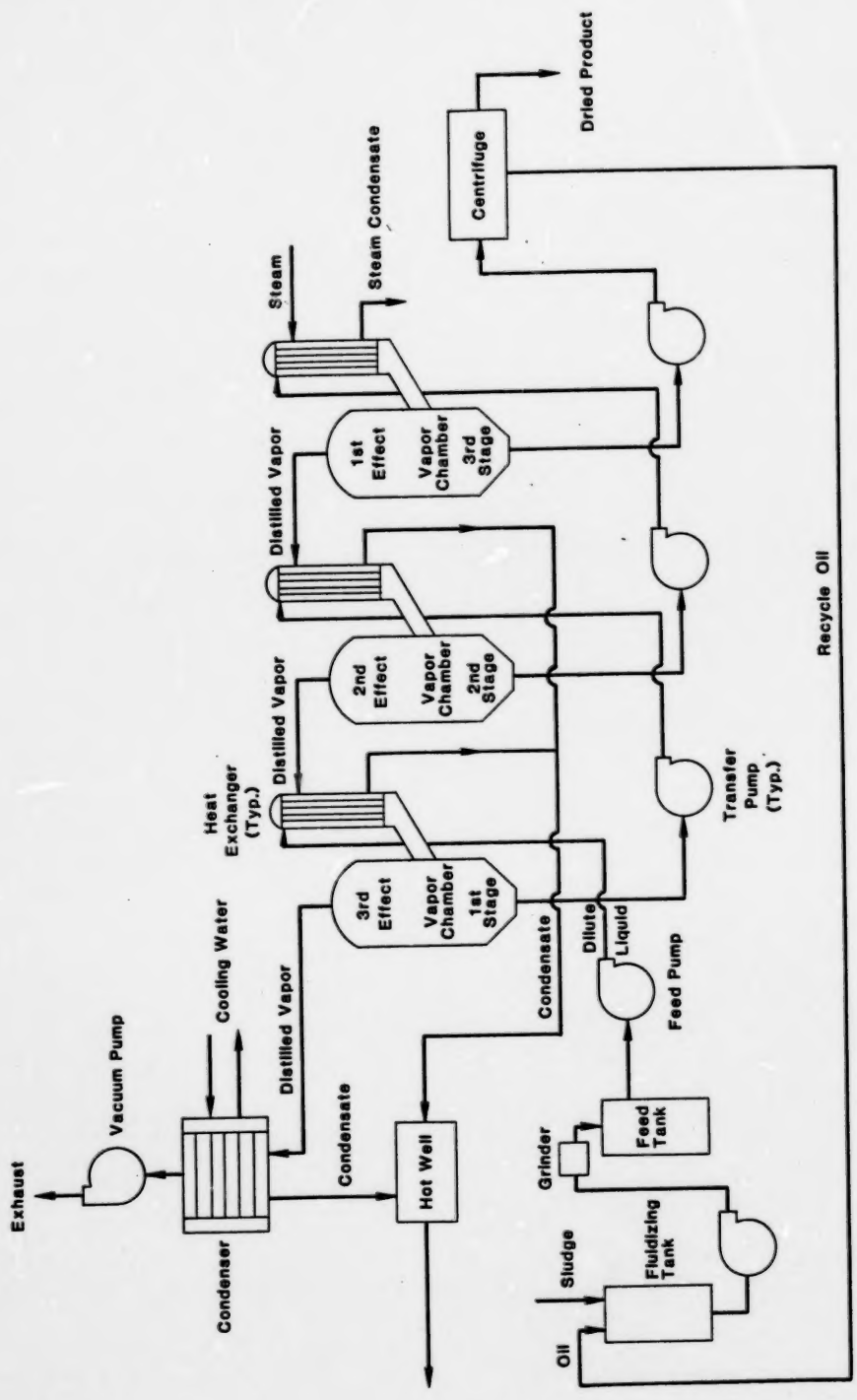

FIGURE 2. Typical Carver-Greenfield Drying Process Schematic (Reference 1).

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The last evaporative stage is usually referred to as the "hot or drying effect". Here temperatures are maintained at approximately 120°C (250°F). The temperatures in preceding effects are progressively lower with increasing vacuum (by means of the condenser and vacuum pump) applied for evaporation.

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TEMPERATURE/LEVEL CONTROLS

The temperatures in the "hot effect" must be sufficient to account for the boiling point rise of the mixture. The boiling point of the mixture increases above that of pure water as the sludge becomes more concentrated. The boiling point of the oil-municipal sludge mixture is 111-119°C (232-247°F).

The low temperatures (maximum 120-130°C, 248-266°F and decreasing water concentrations as temperatures increase in the C-G system do not result in solubilization of any of the organics or denaturization of the sludge protein. The Carver-Greenfield system is a drying technique but is not analogous to heat drying or thermal sludge conditioning.

The level of sludge-oil mixture in the evaporator is critical to heat transfer and must be maintained within specific levels. To accomplish this, the output of the circulating and transfer pumps are automatically throttled in proportion to a measured level change with the exception of the last stage which is controlled by flow to the centrifuge. This has proved to be an effective and uncomplicated means of control for the C-G process.

EXHAUST STEAM

Process steam is introduced into the first effect. The steam condensate in the first effect is returned to the boiler. The condensate from the other effects is returned to a hot well. The condenser and vacuum pump maintains the pressure in the vapor chambers well below atmospheric to permit evaporation at lower temperatures. The vacuum pump also removes any non-condensable gases that are present.

The vacuum pump exhaust is combusted in the boiler or treated for odor control as required and exhausted to the atmosphere. If light fluidizing oils are used, an activated carbon adsorption system is employed to trap the vaporized oils. When the carbon is regenerated, the system returns them to the C-G process. The condensate from the C-G process does not require any special pretreatment as is the case for heat treatment processes (Reference 11).

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The condensate does contain volatile acids and ammonia and a small amount of carrier oil. Considering the small volume and low BOD load, the condensate can simply be returned to the head of the treatment works without any deleterious effect on the treatment process. The condensate represents approximately 5 to 10 percent of the BOD load at a typical facility. Summarized in Table 1 is a comparison of the C-G condensate analysis from various dewatering devices (Reference 1).

PRODUCT-OIL SEPARATION

The dried mixture from the first (hot) effect is typically less than 5 percent moisture content. Lower values of moisture content are easily obtainable depending upon process requirements. Oil content at this point is usually in the range of 80 to 90 percent by weight. This oil consists for the most part of the carrier or fluidizing oil, but also contains oils and grease originally in the sludge which have been solubilized in the fluidizing oil. The first stage of oil/solids separation is usually accomplished by means of a centrifuge. This centrifuge step is capable of reducing the oil content to approximately 30-40 percent by weight. The recovered oil is suitable for recycling as fluidizing oil and provides most of the process oil requirements. In the case of municipal sludge, the likely procedure would be to separate the heavy sludge oil mixture from the fluidizing oil by distillation, recycling the fluidizing oil for use in the C-G process, and using the sludge oil mixture as fuel to generate a portion of the process steam.

Table 1. ANALYSIS OF CONDENSATE FROM C-G PROCESS

Source	No. of Samples	pH	SS ppm	TS ppm	NH_3N ppm	BOD ppm	COD ppm	Acids ppm	Oil ppm
Fukuchiyama	32	4.5	16.8	109	193	3230	292	1390	1.45
LA/OMA Pilot Study Liquid digested sludge	69	9.1	—	—	763	201	348	187	—
Dewatered digested sludge	57	9.7	—	—	1618	3146	1941	1080	—
Thickened waste activated	15	8.6	—	—	642	2015	2076	2003	—

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CLOGGING OF EVAPORATOR TUBES

A gummy phase and subsequent plugging of heat exchangers may occur if the action of the fluidizing medium is inhibited. In this event, the oil to solids ratio becomes unbalanced, viscosity increases as drying occurs and scaling results, eventually causing clogging of the evaporator tubes. The phenomenon behind this problem is the formation of an emulsion. It is an intimate mixture of the oil and water in which the oil particles are so fine that the fluidizing result is completely negated. Emulsified material then behaves as it would without the oil addition. In a four-effect system, for example, about one-fourth of the total water input to the system will be evaporated in each effect. Therefore, each effect will operate at a certain solids to water ratio. Apparently the gummy phase can occur at both low and high ratios of solid to water. The actual ratio depends on the sludge type, carrying oil and other factors. An important part of gummy phase control is the application of solids addback to reduce the formation of emulsions. Addback simply involves recycling dried product, ideally to the fluidizing tank, to maintain a solids to water ratio of 1:3 to the first evaporator. Operating and test data clearly indicates that this technique is extremely reliable and has recently been incorporated in the C-G system at the Coors Brewery. It is important to note that standard process provisions are available to eliminate most gummy phase problems (Reference 1 and 2).

OPTIMIZED OIL RECOVERY-HYDROEXTRACTION

Further oil recovery steps may be desirable depending upon use of product and the particular economics of the installation. High pressure filter presses have been utilized to reduce the oil content to approximately 10 percent. On the other hand, if a light hydrocarbon fluidizing oil such as Isopar AMSCO 140 or Chevron 410B were utilized, economical recovery could be realized by a hydroextraction technique.

The hydroextraction technique can result in almost complete recovery of fluidizing oil and thereby greatly enhance process economics. The use of light oil such as Isopar (boiling point 190-200^{o}C, 372-392^{o}F) will, however, increase the amount of fluidizing oil that distills in the evaporators. This oil fraction is easily removed from the condensate by decanting and coalescing.

OIL FLUIDIZING BENEFITS

Two significant limitations of multi-effect evaporation are increasing viscosity and resistance to heat exchange of the

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slurry as it is concentrated. These limitations are eliminated by the addition of the fluidizing oil. The fluidizing technique offers another advantage in that the oil wets the heat exchanger tubes, thereby decreasing the potential for corrosion, scaling and abrasion.

COMMON PROCESS MODIFICATIONS

The basic C-G process is adaptable to modular application and to a variety of end product uses. For example, the City of Los Angeles has conducted extensive tests on combustion of the dried sludge produced by the C-G process. The report (Reference 13) was actually a Phase II study to develop detailed criteria for design and air emission data for subsequent air quality permits. Other applications include the use of the rotary hearth furnace as in the case of the Eli Lilly plant in Elkart, Indiana (Reference 2 and 11). The soil conditioning product market has also been explored. Modifications of the components within the basic process may be considered for specific projects by the design engineer. However, the basic process is patented by Dehydrotech Corporation.

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SECTION 4

DEVELOPMENT STATUS

INTRODUCTION

Although there are many Carver-Greenfield (C-G) installations in operation, they are mostly used in food processing, pharmaceutical, or similar industrial operations. Several of these facilities process sludges from industrial waste treatment which have characteristics similar to secondary sewage sludge. There are two installations in Japan that treat sewage sludge. The Adolph Coors Brewery at Golden, Colorado has built a C-G plant to process waste activated sludge produced from their brewery waste treatment operation.

The C-G process is not a traditional sewage sludge handling process, and concerns have been raised about the adaptability of this process in municipal sludge treatment operations. There have been specific areas of concern raised about this process in recent years. The most frequently mentioned regards the potential for the heat exchanger tube clogging, oil losses from the system, quality of the process sidestream (condensate), and cost of operation. The City of Omaha had to shut down a C-G installation after operating for a very short period due to severe operating problems. In this case, the shutdown of the Omaha facility should not be viewed as a process failure, but rather as poor planning, design or both. The problems here appear to have been solvable from a technical standpoint, thus providing additional knowledge or the elimination of redundancies in future C-G processes (Reference 2). The potential quality of the process sidestream has also been debated in recent years. In a report to the New York--New Jersey Interstate Sanitation Commission, Camp, Dresser and McKee Inc. (Reference 4), assumed that the quality of such liquid stream (condensate) is similar in nature to that expected from conventional heat treatment of sludge. However, the condensate was a clear liquid and averaged about 2600 mg/l COD, mostly from low molecular weight volatile acids, and about 1400 mg/l NH_3 when processing dewatered digested sludge. In the Hyperion Energy Recovery System (HERS), the condensate from C-G process will be about 1/10th the COD and NH_3 load of the sidestream from typical dewatering (centrifugation) operations. Low condensate CODs (450 mg/l) were also obtained by Villiers

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et al. (Reference 5) in their exploratory studies employing primary sludge.

PILOT SCALE RESEARCH

City of Los Angeles (References 2, 6)

In 1975, the City of Los Angeles operated a trailer mounted pilot scale C-G unit at the Hyperion Treatment Plant. The unit was a single-effect evaporator rated between 200 to 500 pounds of water per hour and operated as a batch process. The types of sludges processed were raw and digested primary sludges, and a blend of undigested primary and waste activated sludge. The following observations were reported by the City:

- The process was capable of drying the type of sludges tested to over 95 percent solids (on moisture content basis).

- The dewatered solids from centrifugation contained 30 to 40 percent oil.

- The process condensate (liquid sidestream) had the following constituent concentrations: oil, 2 mg/l; TDS, 5-16 mg/l; COD, 340 to 1,060 mg/l; NH_3, 150 to 7,170 mg/l. The report concluded that ammonia and COD concentrations would actually be lower than these levels in a four-effect system. This is due to the fact that in a four-effect system, evaporation takes place at a relatively lower temperature in the first three effects. The report concluded that the higher temperatures occurring in a single-effect system would break down more protein, thus releasing more ammonia.

- The fluidizing oil was progressively contaminated, picking up solids from the sludge with each pass through the system.

- Some clogging of the heat exchanger tubes was noticed. Grinding of primary sludge was felt to be essential to prevent such clogging. However, no scaling of the tubes was observed.

- A recommendation was made to test a pilot plant operated in a continuous mode. It was also concluded that the pilot plant should include a sludge grinder and a hydroextraction unit (see LA/OMA Project below).

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Weyerhaeuser Company (References 2, 7)

In 1977, the Weyerhaeuser Company conducted a pilot single effect C-G demonstration study at their Cosmopolis, Washington facility. This was done as a part of a series of pilot tests for dewatering their "bio-pond" sludge. The sludge was generated from paper pulp processing activities and was not similar to municipal sludge in characteristics. Therefore, some caution should be exercised in directly applying these findings to municipal sludge handling operation. The following conclusions were drawn from the study:

- o A dry granular sludge with solids concentration varying from 42 to 81 percent was obtained.
- o Additional processing was recommended to reduce the residual oil. Steam stripping for volatile oils (petroleum base) and pressing for non-volatile (vegetable) oils were thought to be the most efficient way of achieving this.
- o Formation of a gummy phase was observed at certain ratios of solids to water. The first occurred at a solids content of about 30 percent and another at about 90 percent total solids (based on moisture content). However, the report concluded that the problem could be avoided through proper design and operation.
- o Formation of an undesirable oil-condensate emulsion was noticed with the use of Isopar (an Exxon product) as the carrying medium. This was tracked to the heavy use of surfectants in the main plant which ended up in the sludge stream.
- o An odor problem was presented by the non-condensable vapor vented by the vacuum pump.

Adolph Coors Company (References 2, 8)

While investigating potential dewatering methods for waste activated sludge, Adolph Coors Company of Golden, Colorado, conducted a pilot study of the C-G process.

The C-G process was selected as the best process to deal with their waste activated sludge disposal problem. Recommendations for full-scale construction included use of vegetable oil as a carrying fluid; pressing for extraction of oil from dried sludge, and sale of final product as animal feed. A description of their full-scale plant operation is included later in this chapter.

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LA/OMA Project (Reference 2)

A continuous flow pilot-scale demonstration study of the C-G process was carried out by the City of Los Angeles at their Hyperion Treatment Plant under contract with the Los Angeles-Orange County Metropolitan Area (LA/OMA) Project.

The conclusions derived from the pilot plant demonstration are given below. The test objectives are shown in conjunction with the corresponding conclusions.

Objective 1:
To identify operational problems encountered in the continuous flow system.

Conclusion:
The operating problems encountered during the pilot-plant investigation were: solids settling out in the mixing (fluidizing) tank and feed tanks; carry-over from the vapor chamber to the steam condenser; plugging of sludge-oil slurry lines; and dust contamination of the hydroextracted oil. Such problems were attributed to the shortcomings of the pilot-plant design and not the C-G process itself.

Objective 2:
To investigate the efficiency of the hydroextraction process for removal of residual oil in the dewatered solids.

Conclusion:
The hydroextraction process was effective in removing residual oil in the centrifuged solids. Hydroextracted solids contained 1.1 percent oil or less (based on dry weight of solids).

Objective 3:
To identify corrosion problems.

Conclusion:
No scaling of the heat exchanger tube inner walls was observed. It appeared that Isopar L was an effective fluidizing medium. During the investigation no corrosion problem was noticed.

Objective 4:
To determine the extent of heat exchanger tube fouling during continuous operation and the ability of sludge grinding to mitigate the problem.

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Conclusion:

Clogging of the heat exchanger tube nest inlet by fibrous sludge material was prevented by grinding of the sludge feed. Primary sludges definitely require grinding; waste activated sludges may not.

Objective 5:

To determine the characteristics of final products resulting from the system, including liquid sidestreams (i.e., condensate) and exhaust gases.

Conclusions:

- Extracted sludge water (process condensate) contained TDS between 16 and 22 mg/l, COD between 212 and 4,167 mg/l, nitrogen as ammonia between 464 and 1,749 mg/l, and heavy metal concentrations generally below 0.1 mg/l.

- Dried sludge solids (centrifuged solids) contained residual oil ranging between 37.2 and 47.4 percent, total solids between 51.3 and 60.9 percent, and moisture between 1.0 and 7.7 percent. On an oil-free basis, the solids concentration ranged between 87.2 and 98.1 percent, with an average value of 95.7 percent.

- Recirculated oil became contaminated with sludge oils and fine sludge solids. Stripping of the recirculated oil is effective in removing both heavy sludge oils and sludge solids, and would help control the inventory of fine solids in the system.

- Based on limited data, pathogen destruction through the C-G process appeared to be complete.

- System losses of Isopar were due primarily to uncontrolled venting. If vent losses are controlled, potential loss of Isopar should be limited to that contained in the final solids after hydroextraction.

- Major air emissions of concern with the C-G process itself are likely to be hydrocarbons resulting from the volatility of the Isopar. Mix tanks, vacuum pumps, centrifuge, and solids conveying systems were identified as the major sources of such emissions. In a full scale system, provision must be made to collect these vapors, condense them, and direct remaining gases to a boiler or pyrolysis reactor for combustion.

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FULL SCALE FACILITIES (Reference 1)

There are over seventy operating C-G installations. For the most part they are used in industry for drying various industrial waste streams. Two plants, the Fukuchiyama City and Hiroshima plants in Japan, process municipal sludge from conventional activated sludge treatment plants.

A list of full-scale C-G installations is included in Table 2. Three of these installations are discussed.

Adolph Coors Company, Golden Colorado (Reference 1)

Sludge Source. The sludge processed through the C-G process is a mixture of primary and waste activated sludge generated from the on-site treatment works. The waste activated sludge is thickened by air flotation and is blended with the primary sludge. There are no grinding or masceration steps prior to introduction into the C-G process. The C-G process at the Coors Brewery is a four effect system sized for an evaporative rate of 60,000 lbs (27,200 kg) of water per hour.

Oil Fluidization. Sludge is fluidized with a petroleum based oil at a ratio, by weight, of 6 parts oil to 1 part of dry solids. The oil is metered by ratio control of sludge flow.

Steam Source-Temperature/Pressure. The steam source for the C-G installation is the brewery boiler plant. High pressure steam is supplied and reduced through turbine driven pumps to 344,700 to 413,700 Pa (50 to 60 psi) for feed into the fourth effect. The steam is fed into the hot effect at 145°C (290°F). Vacuum in the effects is sustained by a 25 HP vacuum pump. This results in a temperature and pressure distribution as indicated in Table 3.

Evaporation. The evaporative efficiency of the Coors facility averages 3.2 This means that 3.2 kg of water are evaporated for every kg of steam added. In addition, the protein in the feed sludge passes through the process undamaged and is available in the end product. All four effects at Coors are insulated. The insulation appears to be quite effective, since the vapor chamber operating floor is comfortable. The insulation also improves the thermal efficiency of this installation by minimizing heat loss.

Operating Procedures. The typical composition of the oil-solids mixture leaving the hot effect is 88 percent oil, 9 percent solids and 3 percent water. After centrifuging, the oil content is reduced to approximately 35 percent. A high pressure filter press step following the centrifuge reduces the

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TABLE 2. CARVER-GREENFIELD PLANT INSTALLATIONS (Reference 1)

Customer	Locations	Present Day Status	Feed Material	No. of Evap. Effects	Plant Capacity lbs. of water/hr	Plant Capacity lbs. of solids/hr	Disposition	Start up Date
Independent Mfg. Co.	W. Phila. PA	Sold business on death of owner (1st commercial plant); operated satisfactorily while in operation.	Fat and bones from supermarkets and deboning plants 5 tons/hr 25-35% water.	1 (2 stages)	2500	5000 fat 2500 solids	Animal feed (poultry)	1961-74
Hershey Estates	Hershey PA	Deactivated since Hershey entered a regional facility; operated satisfactorily while in operation.	Primary and secondary sludge (trickling filter) Dow Pak 6-8% air flotation sludge.	3	9000	600	Burned in solids handling boiler to produce steam	1964-74
Allen Products Company	Crete NE	Operating satisfactorily	Dog food wastes by air flotation combined with activated sludge at about 10% concentration	2	6000	660	Sale of fat and solids for animal feed	1970
Allen Products Company	Allentown PA	Operating satisfactorily	Same as Crete Plant	2	6000	660	Same as Crete Plant	1970
Nestle Company	Freehold NJ	Concentrated to 50% only. Operating satisfactorily	Coffee wastes at 1% concentration	4	80,000	800	Landfill	1970
Eli Lilly & Co.	Clinton IN	Expanded to larger plant in 1977; see below.	Pharmaceutical plant wastes at 2-4% concentration	3	30,000	600-800	Burned in boiler furnace but slagging of salts occurred; modified by boiler redesign	1970-78
Eli Lilly & Co.	Clinton, IN	Expanded plant; pyrolysis added producing fuel gas for boiler. Evaporator runs essentially self autogeneous; operating satisfactorily	Pharmaceutical plant wastes at 2-4% concentration.	4	60,000	1200-2000	Operations of pyrolyzer avoids slagging and particulate problems. Ash to landfill.	1978
El Paso Natural Gas	Jal, NM	Originally experimental pilot plant	Brackish water	1 (2 stages)	2000	10	Landfill-sealed containers	1972
Demonstration Plant Ebara Infilco Co.	Tokyo Japan	Used for demonstration on sewage sludge	Sewage sludge	3	2000	100		1973
City of Hiroshima	Japan	Designed and installed by Licensee Ebara-Infilco Co. Operating satisfactorily	Sewage sludge	4	100,000	2000	Burned in solids handling boiler	1975
Upjohn International	Cuernevaca Mexico	Plant designed; equipment purchased and fabricated; plant not installed because Mexico relaxed waste treatment laws.	Pharmaceutical wastes	2	9000	600	Pyrolysis in the future	1975

Cont'd

TABLE 2. CONTINUED, p.2

Customer	Location	Present Day Status	Feed Material	No. of Evap. Effects	Plant Capacity lbs. of water/hr.	Plant Capacity lbs. of solids/hr.	Disposition	Start up Date
Molkerei J.A. Maggle	Raitmehring W. Germany	Pilot Plant	Dairy and food products	1	200	200	Food products	1975
City of Fukuchiyama	Japan	Designed and installed by Licensee Ebara-Infilco Co. Operating satisfactorily.	Primary and waste activated sludge at 4.5-5.0% concentration.	3			Burned in solids handling boiler.	1976
Adolph Coors Company	Golden, CO	Operating satisfactorily.	Brewery treatment plant sludge 4% concentration. 60-70% waste activated 30-40% primary.	4	60,000	2500	Fuel-start Landfill-present Animal feed-1980	1977
Cadbury (Peter Paul)	Hazelton PA	Plant had reducing sugar problem; problem resolved; now customer wants more automatic operation; plant design being reviewed for this operation.	Chocolate waste 2% concentration	2	1500	30	Burned in existing package boiler.	1978
Friendship Dairy	Friendship NY	Operating satisfactorily.	Milk whey byproduct from cottage cheese manufacture	1 (2 stage)	3500	2500	Sold as animal feed; future as a food product.	1978
Iridania Co. (Smogless Co.)	Ferrara Italy	Started operating late 1979	Fermentation molasses waste from alcohol production.	2	11,000	12,000	Fuel gas from pyrolysis.	1979
Societa Chimica Dauna (Smogless Co.)	Manfredonia Italy	Design and equipment purchasing	Petrochemical activated sludge	3	4000	550	Fertilizer	1980

* Since 1982, only waste activated sludge has been processed by the C-G process in an effort to reduce the requirements for oil.

Cont'd

TABLE 2. CONTINUED, p.3

Customer	Locations	Present day Status and Repeat Plants	Feed Material	No. of Evap. Effects	Plant Capacity Pounds/Hr.	Disposition	Start-up Date
Nick Buecher & Sons	Chicago, IL	Operating satisfactorily	Rendering plant waste	2	60,000	Animal Feed	1965
Enterprise Animal Oil Company	Philadelphia, PA	Sold - no longer in operation; operated satisfactorily while in operation	"	2	10,000	"	1965-70
Bookey Packing Co.	Des Moines, IA	Operated satisfactorily	"	2	20,000	"	1965
Pine States By-Products	S. Portland ME	Operating satisfactorily	"	2	9,700	"	1965
CUI International (Utah By-Products)	Ogden, UT	Operating satisfactorily	"	2	20,000	"	1966
Cape Charles (Reedville Oil)	Cape Charles VA	Shut down because of fish scarcity; operated satisfactorily while in operation.	"	2	50,000	"	1966
Kavanaugh Industries (Lynchburg)	Lynchburg, VA	Operating satisfactorily	"	2	13,200	"	1966
Modesto Tallow Co.	Modesto, CA	Operating satisfactorily	"	2	40,000	"	1966
Packerland Packing Co.	Green Bay WI	First plant operating satisfactorily	"	2	10,000	"	1966
Green Bay Soap Co.	Green Bay WI	Operating satisfactorily	"	2	25,000	"	1967
Lomex Co. (Longeuil Meat Exporting Co.)	Montreal Canada	Operating satisfactorily	"	2	40,000	"	1967
Midland By-Products, Inc. (Swingle)	Crete, NE	Operating Satisfactorily	"	2	13,200	"	1967
Milwaukee Tallow Co., Inc.	Milwaukee, WI	First plant shut down; installed second plant; operated satisfactorily.	"	2	60,000	"	1979
		Second plant operating satisfactorily.	"	2	60,000	"	1979
Canada Packers Ltd	Toronto	Operating Satisfactorily	"	2	20,000	"	1968

Note: From processing of bones, fat, viscera of beef, fish, poultry and hogs; usual composition - 60% water, 20% solids, 20% fat.

TABLE 2. CONTINUED, p.4

Customer	Locations	Present Day Status and Repeat Plants	Feed Material	No. of Evap. Effects	Plant Capacity Pounds/Hour	Disposition	Start-up Date
National By-Products	Clinton, IA	First plant; operating satisfactorily	See previous description	2	25,000	Animal Feed	1968
Norfolk Tallow Co.	Norfolk, VA	Operating Satisfactorily	"	2	20,000	"	1968
J.M. Schneider, Ltd.	Kitchener, Ont., Canada	"	"	2	18,500	"	1968
Krey Packing Co.	St. Louis, MO	"	"	2	14,500	"	1969
J. P. Allan & Co.	Stockton, CA	"	"	2	30,000	"	1970
Armour Foods (Wilson)	Hereford, TX	"	"	2	20,000	"	1970
Central Bi-Products	Redwood Falls, MN	"	"	2	20,000	"	1970
Dubuque Packing Co.	Dubuque, IA	"	"	2	20,000	"	1970
Packerland Packing Co.	Green Bay, WI	Second plant; operating satisfactorily	"	2	20,000	"	1970
Lomex (Longueuil Meat Company)	Montreal, Canada	Operating Satisfactorily	"	2	20,000	"	1971
Pepcol Packing Co.	Denver, CO	"	"	2	30,000	"	1971
Prosper DeMulder	Warwickshire, England	First plant; operating satisfactorily	"	2	50,000	"	1971
Great Mark Western	Quincy, MI	No longer in business; operated satisfactorily while in operation	"	2		"	1971
Vereinigte Tiermehl-fabriken GMBH	Mering Germany	Operating satisfactorily	"	2	22,000	"	1972
"	Heufekd Bad Aibling Fed Rep of Germany	"	"	2	22,000	"	1972
"	Westphalia Germany	"	"	2	22,000	"	1972
Alberta Processing Company	Calgary, Alberta, CA	First Plant; operating satisfactorily	"	2	30,000	"	1973
Cuyahoga Con., Inc.	Cleveland, OH	Operating satisfactorily	"	2	60,000	"	1974
Farmers Union Marketing & Processing Assoc.	Long Prairie MN	"	"	2	40,000	"	1974
Plymouth Fertilizer	Plymouth, Ind.	"	"	2	30,000	"	1974
Packerland Packing	Chippewa Falls, Wis	Third plant-operating satisfactorily	"	2	45,000	"	1975

TABLE 2. CONTINUED, p.5

Customer	Locations	Present Day Status and Repeat Plants	Feed Material	No. of Evap. Effects	Plant Capacity Pounds/hour	Disposition	Start-up Date
Perdue, Inc.	Accomac, VA	Operating satisfactorily	See above description	2	35,000	"	1975
Prosper DeMulder	Ings Road Doncaster, Yorkshire England	Second plant-operating satisfactorily	"	2	60,000	"	1975
Wilson Pharmaceutical Company	Chicago, IL	Shut down beef operation in Chicago; sold plant to Darling Bros. Operated satisfactorily while in operation. See below.	"	2	60,000	"	1975
Darling Delaware, Inc.	San Francisco, CA	Operating satisfactorily. Purchased from Wilson; moved to California.	"	2	60,000	"	1977
Ryder Rendering	Matamoras, PA	Operating satisfactorily	"	2	30,000	"	1975
West Coast Reduction	Vancouver, B.C.	"	"	2	30,000	"	1975
Robert Wilson & Sons, Ltd.	Cahir, Ireland	"	"	2	60,000	"	1975
Alberta Processing Company	Calgary, Alberta Canada	Second plant; operating satisfactorily.	"	2	45,000	"	1976
National By-Products	St. Louis, MO	"	"	2	30,000	"	1976
National By-Products	Wichita, KS	Third plant; operating satisfactorily	"	2	30,000	"	1977
Ontario Rendering	Dundas, Ont.	Operating satisfactorily	"	2	60,000	"	1977
Cope Rendering	Moultrie, GA	"	"	2	20,000	"	1978
Lomex (Longueuil Meat Company)	Montreal Canada	Third plant; operating satisfactorily.	"	3	30,000	"	1978
Vancouver Processing Ltd.	Canada	Operating satisfactorily	"	2	60,000	"	1979
B.V. Chemische Bedrijven Van De Neb	Holland	Started operating	"	2	25,000	"	1979
B. V. Ned Thermo Chemische Fabrieken	Holland	Started Operating	"	2	25,000	"	1979
Prosper DeMulder	Yorkshire, Eng.	Third plant - not completed	"	2	41,500	"	1980
Cabota	Spain	Designed but not constructed	"	2			1980
Dubuque Packing Co.	Dubuque, IA	Operating satisfactorily	"	2	29,000	"	1970

TABLE 3. TEMPERATURE AND PRESSURE DISTRIBUTION AT COORS FACILITY.

Effect No.	Temperature F^{o}	Temperature C^{o}	Pressure psia	Pressure Pa x 10^3
1	120	50	1.5- 2	10.3- 13.8
2	150	65	3 - 4	20.7- 27.6
3	200	95	7 - 9	48.3- 62.1
4	275	135	20 -22	137.9-151.7

oil content below 10 percent. The recovered oil is recycled to the fluidizing tank. The dry material can be conveyed directly to storage bins or is pelletized prior to storage. Presently it is trucked to a landfill on a weekly basis. The temperature in the storage bins are continuously monitored. Operating records indicate that the temperatures have never exceeded $50^{o}C$ ($120^{o}F$).

Waste Flow. The vacuum pump exhaust leaving the first stage evaporator is condensed before being discharged to a natural gas fired odor furnace where combustion temperatures reach $760^{o}C$ ($1400^{o}F$). Plant effluent is used as condenser cooling water. The condensate from the exhaust stream is combined with condensate from each effect and conveyed to a hot well. The combined condensate undergoes three stages of treatment or polishing. The first stage is oil-water separation in an American Petroleum Institute separator. The second is fabric filtration for suspended solids removal. The third stage is passage through a coalescer for removal of the trace amounts of oil. The entire condensate treatment is a closed system. The condensate is then returned to the treatment works.

Maintenance. No special maintenance problems associated with the C-G system have been reported. Routine maintenance as is necessary in any system having pumps and valves is practiced. The most noticeable maintenance item is the replacement of pump seals.

Principal Observations.

- The C-G process at the Coors Brewery is fully automated and utilizes standard instrumentation and control loops.
- The gummy-phase or plugging of the heat exchangers does not occur when operational parameters are within

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proper limits and the process is easily controllable to maintain those limits.

- An add-back feature which involves recycling a portion of the hot effect discharge to the feed of the preceding effect has been incorporated into the piping to eliminate the gummy-phase even when feed solids are below limits (design values).

- There are no odors or visible emissions apparent from the vacuum pump exhaust after treatment.

- The dry material has an odor characteristic of the materials processed (brewery odor).

- The operators are representative of the type of operator found in municipal operations. They have had no special training other than that received in-house.

- The condensate, although relatively high in COD (5000 mg/l) and BOD (3000 mg/l) can be freely returned to the treatment works with no adverse effect on the treatment process. The BOD of the condensate represents less than 10 percent of the treatment plant influent BOD.

- Total destruction of pathogens based on coliform tests.

Allen Products Company (ALPO), Allentown, Pennsylvania (Reference 1)

The C-G installation at ALPO was started up in 1970. It consists of a two-effect evaporator train originally designed for an evaporative rate of 6,000 lbs (2,720 kg) of water per hour. The system is presently operated at 8,000 lbs (3,630 kg) per hour with no difficulty.

The C-G process at ALPO is operated on an as-needed basis. The process is shut down and started up intermittently. A schematic of the C-G process at the ALPO facility is illustrated in Figure 3.

A good quality tallow is recovered from the waste stream eliminating the need for make up oil. Tallow is also marketed periodically as storage reserves build up. The feed ratio is 6 parts oil to 1 part dry solids by weight.

Sludge Source. Two separate waste streams feed the C-G process. The proportions of the two wastes vary continuously.

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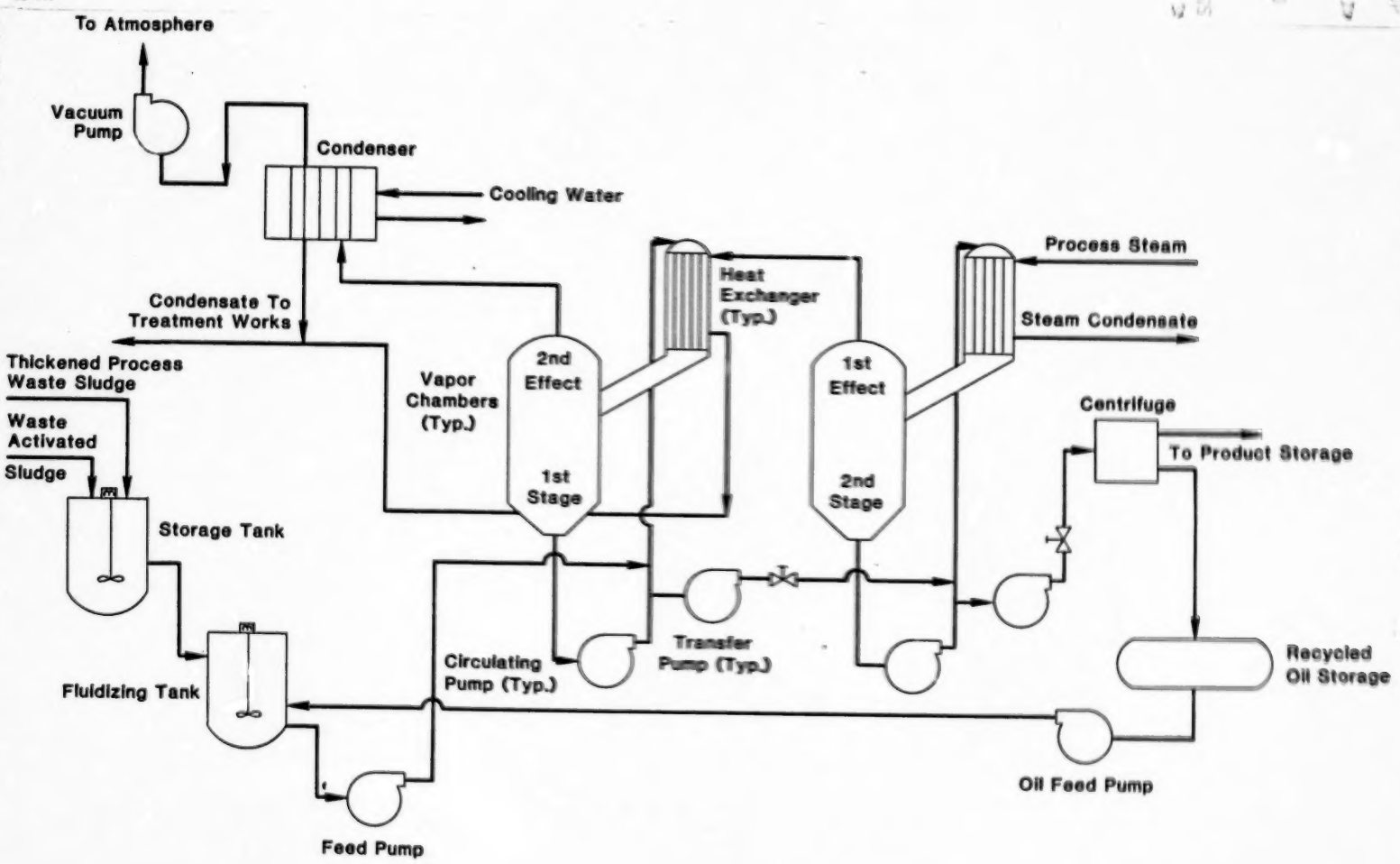

FIGURE 3. C-G Process Flow Schematic; Allen Products Company (ALPO) Allentown, Pennsylvania (Reference 1).

The first stream consists primarily of the wastes produced by the processing of frozen meats. The second component of the influent is waste activated sludge generated at the on-site treatment works. The combined feed to the C-G system is at a solids content of 11 percent, of which approximately half is fats.

Steam. Process steam from the manufacturing plant boiler is fed into the hot effect maintaining a temperature ranging from 110-115°C (230-240°F). The temperature in the cold effect is approximately 50°C (120°F). The cold effect operates at a vacuum reading of 9,650 Pa (25 inches Hg or 1.4 psia). Operating data recorded at ALPO reports an evaporative efficiency of 80 percent which translates to 1.6 lbs of water evaporated for every pound of process steam. This value compares well with the design value.

Principal Operating Features. The C-G process is run intermittently as stored sludge volumes dictate. The only oil separation step at ALPO is removal by batch operation in a basket type centrifuge. Oil reduction of approximately 50 percent is achieved. The end product has a typical oil content of 35-40 percent and a moisture content of 2 to 3 percent, as reported by ALPO operators. The dried product is marketed for eventual use as animal feed.

The vapor stream from the cold effect is passed through a condenser and exhausted to the atmosphere without further treatment. Condensate from the heat exchangers and condenser is collected in a central channel and returned to the head of the treatment works.

Maintenance. The only noteworthy maintenance items reported were similar to those at Coors; that is, pump seal replacement and periodic cleaning of condenser tubes with an acid solution.

Principal Observations.

- The vacuum exhaust imparts no noticeable odor to the surrounding environment. It was reported, however, that some odor problems do arise if septic sludge is processed. In addition, there were no visible emissions during the inspection.

- The condensate, as observed, was clear and odor free. Condensate is returned to the treatment works without upsetting the activated sludge process.

- The dry materials handling phase of the process imparted a mild odor to the building interior.

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- The evaporators were not insulated, and high temperatures were evident in portions of the building.

- Heat exchanger clogging has not been experienced.

City of Fukuchiyama, Japan (Reference 1)

The Fukuchiyama City plant serves a population of 60,000 to 70,000 people. The influent sewage consists of flow from sewered residential areas, commercial and industrial sources within the service area and collected "night soil". The plant is typical of activated sludge treatment plants in the United States.

The C-G process at the Fukuchiyama City facility is a triple effect system sized for a evaporative rate of 14,000 lbs (6,350 kg) per hour. The process is designed for ultimate operation on a 24-hour basis.

Sludge Source. The sludge processed by the C-G system is a mixture of primary and waste activated. The sludges are thickened separately and blended prior to the fluidizing step. The primary sludge is thickened by gravity to a solids content of 8-9 percent. The waste activated sludge is thickened by air flotation to a solids content of 4.5 percent. The blended sludge as processed has an average solids content of 5 to 6 percent.

Principal Operating Features. The C-G process at the Fukuchiyama Plant is operated for approximately 8 hours per day. The process is started up every morning and produces a dried product within one hour. The sludge is fluidized with a heavy grade fuel oil. A schematic of the C-G waste heat recovery system is illustrated on Figure 4.

Steam Source. The source of steam for the C-G process is the plant boiler which utilizes the dried product for fuel. Steam is fed to the hot effect at approximately 296,500 Pa (43 psia). The evaporative efficiency at Fukuchiyama City is 75 percent. A typical pressure and temperature profile for the Fukuchiyama facility is presented in Table 4.

Waste Condensate. The condensate from the effects undergoes a gravity oil separation step and is then returned to the aeration tank. The condensate BOD represents approximately 5 percent of the plant influent BOD loading. The condensate is clear and colorless but does contain volatile organic acids derived from the sludge.

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FIGURE 4. C-G Heat Recovery Process Flow Schematic: City of Fukuchiyama, Japan, Sewage Treatment Plant (Reference 1).

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TABLE 4. TEMPERATURE AND PRESSURE PROFILE - FUKUCHIYAMA

Effect No.	Temperature (^{o}F)	Temperature (^{o}C)	Pressure psia	Pressure Pa x 10^{3}
1	149	65	0.5-0.9	3.4-6.2
2	176	80	3.2-4.5	22.1-31.0
3	212	100	12.5-14.0	86.2-96.5

Oil-Moisture Difficulties. The oil to solids ratio utilized at Fukuchiyama is 6:1 oil to dry solids by weight. This results in a mixture leaving the hot effect ranging between 75 and 80 percent oil. Data obtained from the Fukuchiyama City plant shows that an oil content reduction of approximately 50 percent is obtained by the centrifuge step.

Boiler Facilities. The dried mixture is presently mass fired in the boiler to produce process steam. Auxiliary fuel is used for process start-up to maintain a minimum boiler temperature during intermittent operations and whenever steam production is insufficient. Overall, auxiliary fuel consumption is reported to be less than 0.115 cu m of fuel oil/metric ton dry solids (25 gallons/ton). Overall oil consumption for the C-G process and boiler operations is reported to be approximately 0.42 cu m per metric ton dry solids (100 gallons/ton). The make-up fuel oil is required because of the relatively low solids content in the C-G process influent.

The boiler exhaust gas control train at Fukuchiyama City consists of a cyclone and a wet scrubber. The average particulate emission reported equates to approximately 0.75 kg particulate per metric ton of sludge solids (1.5 lbs/ton). The average SO_x concentration in the exhaust gas is 105 ppm. These values are well within the limits imposed by the local regulatory agencies and are in general conformance with regulations in effect in many areas of the United States.

Maintenance. The operators of the C-G process at the Fukuchiyama City plant report that no special maintenance procedures are required for the facility. The type of maintenance operations performed are those normally associated with sewage treatment works.

Principal Observations.

- Operation of the C-G system at Fukuchiyama City is handled routinely with all other treatment operations.

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- Odor was not observed to be a problem either in the liquid or dry materials handling phases.

- The evaporator effects are not insulated and are installed outside. Insulation would improve thermal efficiencies.

- The C-G system performs slightly better than design expectations.

- The gummy-phase has never occurred at Fukuchiyama.

- The lack of corrosion further supports the theory that the oil acts as an inhibiting agent.

- Foaming in the effects has not occurred.

- Boiler stack emissions, based on test data, can meet most present air pollution codes.

- Condensate is returned to the aeration tank without any effect on the treatment process.

- Make-up fuel oil to the boiler is required because of the low solids content in the C-G influent.

AVAILABLE EQUIPMENT/HARDWARE

The C-G process is patented by Dehydrotech Corporation (formerly Carver-Greenfield Corporation) and is marketed under exclusive license arrangements by the Foster Wheeler Energy Corporation. The patented process equipment and appurtenant hardware can be negotiated directly with Dehydrotech. Currently, Foster-Wheeler is developing plans and specifications for all C-G equipment.

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SECTION 5

TECHNOLOGY EVALUATION

PROCESS THEORY

Process Description (Reference 3)

The C-G process is a drying technique utilizing the principle of multi-effect evaporation. Water is extracted from sludge by evaporation using multiple-effect evaporators. The sludge to be processed should first be thickened or dewatered to reduce the amount of water to be evaporated, and thereby reducing energy consumption. Thickened sludge is then mixed with an oil, such as No. 4 fuel oil or Isopar-L (an Exxon product), in the fluidizing tank at a suggested ratio of 1 part dry solids to 5-10 parts oil (see Figure 5). By use of an oil, fluidity is maintained in all effects of the evaporation cycle, formation of scale is eliminated and corrosion of the heat exchangers is minimized. The sludge/oil slurry is then pumped to the multiple-effect evaporator where water is vaporized and the remaining solids/ oil mixture is first separated by gravity and then centrifuged to further separate the oil and solids. An additional step, called hydro-extraction, is sometimes used to maximize oil removal by steam stripping. The oil is recycled and reused while the solids are discharged for further processing or disposal. Heavy oils contained in the sludge dissolve in the carrier oil and can be recovered as fuel oil by simple distillation.

Principle of Multiple-Effect Evaporation (Reference 1)

A schematic diagram of a single effect evaporator is illustrated in Figure 6. In a single effect evaporator the liquid to be evaporated is pumped into a heat exchanger (generally into a tube nest). Steam is also introduced into the chamber (generally on the outside of the tubes). As heat is transferred across the tubes from the steam to the liquid in the tubes, the steam is condensed. The condensed steam is then removed from the heat exchanger. At the same time, a portion of liquid within the heat exchanger evaporates and is transferred into the vapor chamber along with the remaining liquid phase. In the vapor chamber the gases and liquid phases

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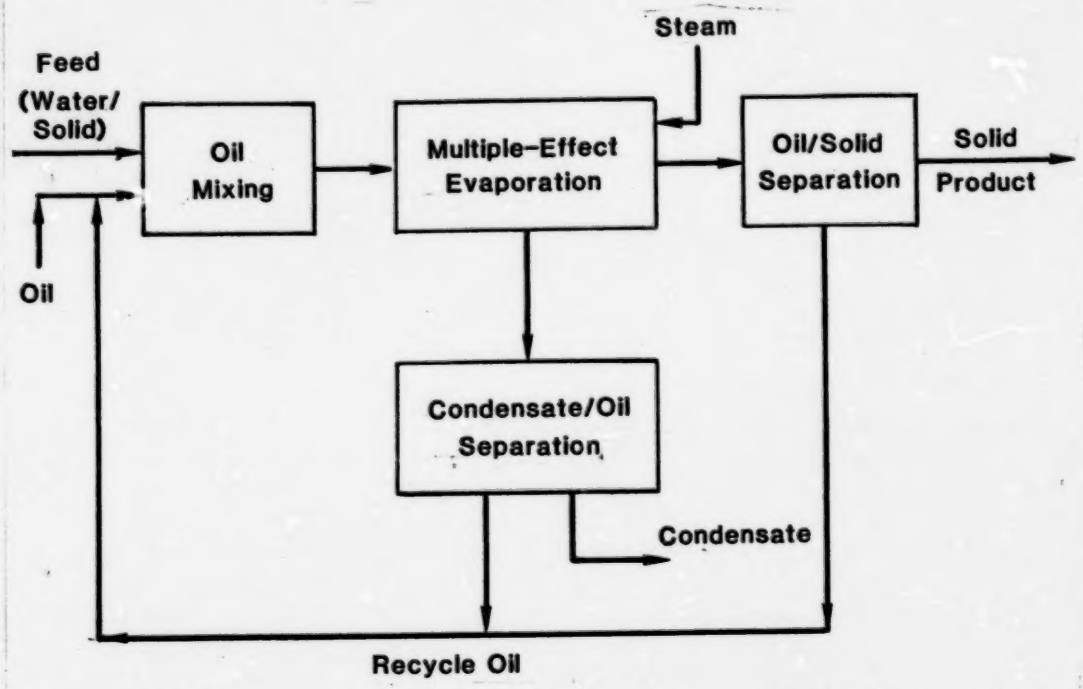

Figure 5. Carver-Greenfield Block Flow Diagram (Reference 3)

are separated. The liquid is withdrawn. The distilled vapor then flows to a condenser. In the condenser, cold water or air is used to cool the vapor below its dew point. The condensate and remaining vapor from the condenser are then withdrawn.

In the single effect evaporator, vapor from the boiling liquid is condensed and usually discarded. The single effect evaporator does not utilize the heat contained in the vapor and therefore does not optimize the use of the original process steam. Single effect evaporators are used predominantly where the required capacity is small and the process steam inexpensive.

To evaporate 0.5 kg (one pound) of water from a solution in a single effect evaporator, approximately 1320 kj (1250 Btu's) are required. This translates to approximately 0.6 kg (1.25 lbs) of saturated steam at 861,850 Pa (125 psia). In order to provide a more economical utilization of steam, the multi-effect evaporator principle is employed. The first or "hot effect" of a multi-effect system functions in the same manner as a single effect evaporator. That is, steam is fed

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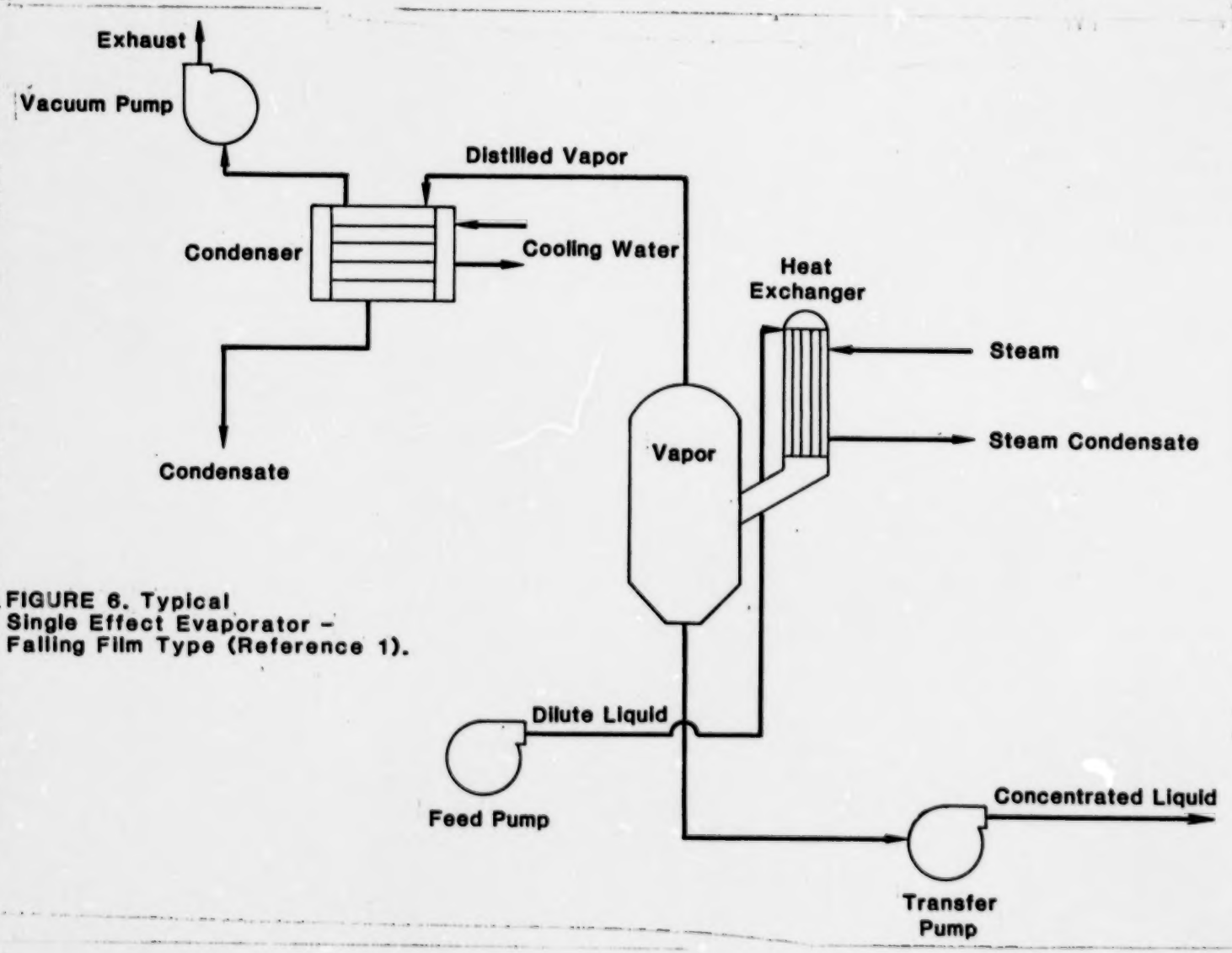

FIGURE 6. Typical
Single Effect Evaporator –
Falling Film Type (Reference 1).

from an outside source, and by means of heat exchange is used to evaporate a portion of the water in the solution or slurry. In the multi-effect evaporator, the vapor is reused in successive effects as illustrated in Figure 7.

The vapor from each effect is utilized in subsequent effects to evaporate a portion of the liquid in that effect. The temperature of the vapor from the first effect is lower than that of the process steam. Similarly, the vapor temperature in each subsequent effect is lower than that of the preceding effect. To accomplish the desired evaporation, the pressure in each successive effect must be lowered. At lower pressures the solvent or water will evaporate at lower temperatures permitting evaporation even in the last or so called "cold effect". The effect of pressure on the boiling point of water is illustrated in Table 5.

TABLE 5. EFFECT OF PRESSURE ON BOILING POINT OF WATER

Pressure (psia)	(Pa)	Boiling Point (^{o}F)	Boiling Point (^{o}C)
1.0	6.9	101.74	38.75
2.0	13.8	126.08	52.25
5.0	34.5	162.24	72.35
10.0	68.9	193.21	89.56
14.7	101.4	212.00	100.00

If the process steam is fed to the first effect of a multiple-effect evaporator above the boiling point of the liquid to be evaporated (at a given pressure), then 1.25 kg of steam will evaporate about 1 kg of water. The water vapor evaporated will then serve as the steam for the second effect and so on for each successive effect. The steam requirement of 1.25 kg of steam per 1 kg of water evaporated for single effect evaporation can be theoretically reduced to 0.42 kg steam per kg water, 0.31 kg steam per kg water and 0.25 kg steam per kg water for 3, 4, and 5 effect evaporators respectively. This, of course, does not consider radiation heat loss and the energy required to reduce the pressure in successive stages.

PROCESS CAPABILITIES AND LIMITATIONS

A simplified materials balance for a typical four-effect C-G process is illustrated in Figure 8.

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FIGURE 7. Typical Multi-Effect (Triple Effect) Evaporator - Falling Film Type (Reference 1).

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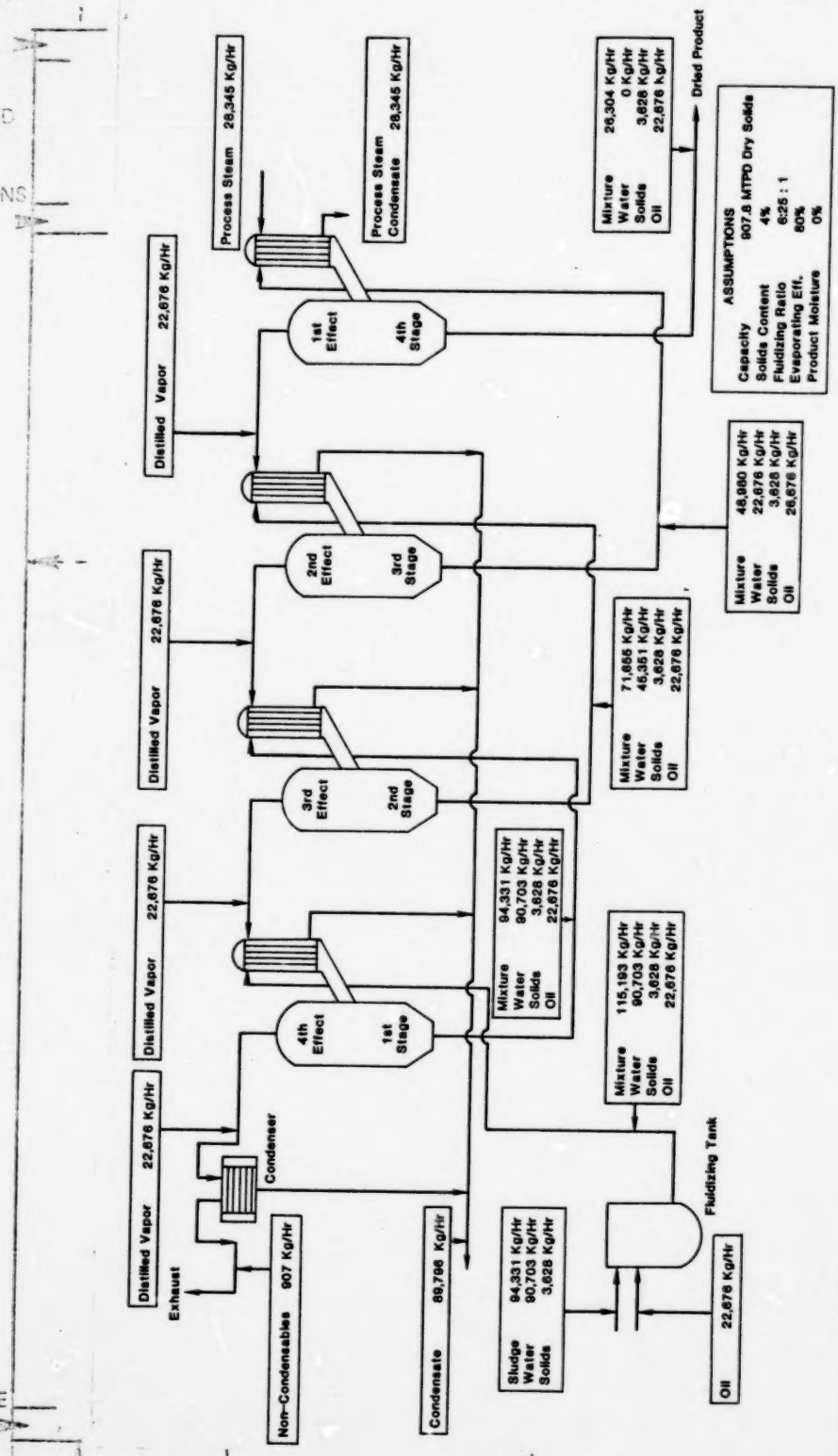

FIGURE 8. Materials Balance – Four Effect Carver–Greenfield Process (Reference 1).

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The capabilities of the C-G process are listed below:

- The C-G process is capable of drying aqueous solutions or slurries with a wide range of solids contents (4 to 45 percent). The process can handle any type of municipal sewage sludge and can be designed to handle any feed concentration or can evaporate water to any degree of dryness.

- Because C-G uses multiple effect evaporation, it consumes only a fraction of the energy required by other heat drying processes.

- Assuming the dried sludge is used as a fuel, the process may be self-sufficient in energy and in some cases provides excess energy for export.

- It removes poly-chlorinated bi-phenyls (PCB) which are destroyed when sewage oil is used as a fuel in a boiler.

- The C-G process produces a dry, easy-to-handle product which is sterilized by heating to above 120°C (250°F) during evaporation. All pathogens, viruses, bacteria, etc. are destroyed.

- Since it operates in a completely closed system, odors are contained within the system. The odoriferous and other non-condensable gases contained in the sludge feed which evolve during evaporation can be added to the air intake of the boiler for combustion.

- The greatly reduced volume of fully dried sterile product may be safely disposed of with minimum land use, or may be used as a fertilizer and soil conditioner.

- The dried solid product can be stored for an indefinite period.

Two significant limitations of multiple-effect evaporation are increasing viscosity and resistance to heat exchange of the liquid as it is concentrated. If the increase in viscosity is sufficient, the material can clog or scale the evaporator tubes of the heat exchanger and prevent evaporation. To eliminate this problem, the material must be kept in a fluid state in each effect. This can be accomplished by using a fluidizing medium. The incorporation of a fluidizing oil with the multiple effect evaporators is the basic principle of the C-G process.

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It would appear that infinite evaporation would result from the use of an infinite number of effects. Theoretically for a single-effect unit, 2300 kj per kg of water removed (1000 Btu's per pound) is required, and for a double-effect unit, 1150 kj are required per kg of water removed (500 Btu's per pound), etc. Several factors, however, limit the number of effects practicable in a system. Each effect of a multi-effect evaporator operates only on a fraction of the total temperature drop across the system. Since the total drop is seldom larger than that employed in single-effect evaporator, the capacity per unit area of heating surface is reduced proportionately. Thus, savings in fuel requirements may be realized through multi-effect operation, but equipment costs will be greater. Also, heat is lost to the atmosphere through the surfaces of the system, as well as being removed by the product streams. Usually 3 or 4 effects are economical, but the actual number is largely influenced by prevailing fuel costs.

DESIGN CONSIDERATIONS

Full-Scale Carver Greenfield Process (Reference 2)

A detailed diagram of a four-effect, full-scale C-G process is presented in Figure 9 and is described below. The system components were assembled by Dehydrotech Corporation and Foster-Wheeler Energy Corporation at the request of the LA/OMA Project (Reference 2).

Referring to Figure 9, feed sludge enters the fluidizing tank where it is mixed with fluidizing oil. The latter is a mixture of recycle oil and dry sludge slurry obtained from the fourth stage evaporator. Capability for dry sludge slurry recycle, referred to as "addback", is included to improve the suspension qualities of the feed sludge and oil mixture. It also alleviates problems associated with gummy phase formation. A ratio of one part feed solid (dry basis) and one part of recycled dry slurry solids (oil free basis) has been recommended by the manufacturer. This depends in part on the input solids content.

The slurried mixture in the fluidizing tank is then pumped to a grinder having a 1/4-inch size screen. Discharge from the grinder is fed by gravity to the evaporator feed tank fitted with an agitator to maintain a uniform slurry consistency.

Slurry is then pumped to the four effect evaporator system. In the evaporator system, temperature of the feed slurry increases from stage to stage whereas the water vapor

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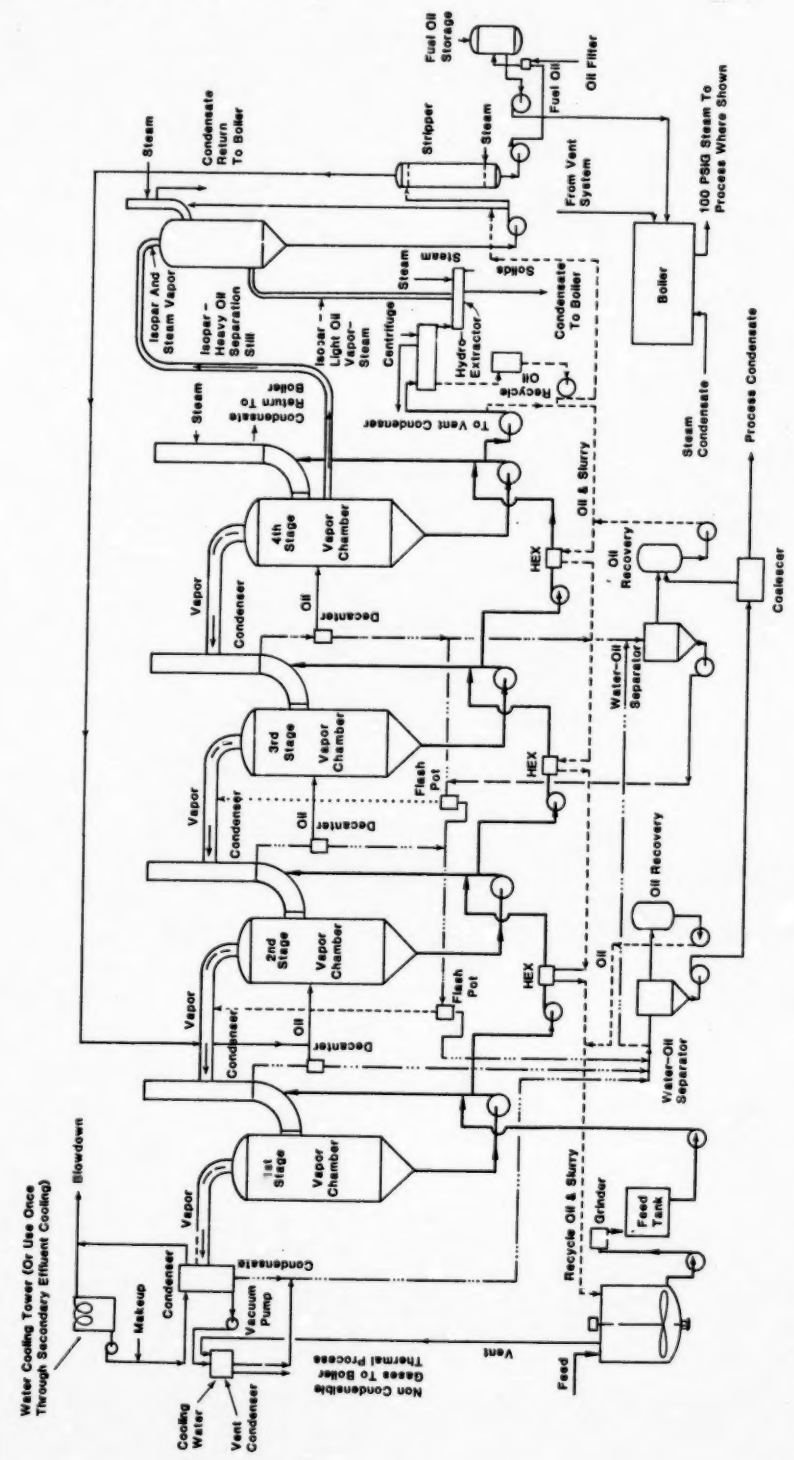

FIGURE 9. Flow Diagram of a Full Scale Four–Effect Carver–Greenfield Process (Reference 2).

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flowing in the opposite direction decreases in temperature from one effect to the next. The evaporation of liquid continues through the system by maintaining progressively lower pressures in each effect and, therefore, progressively lower boiling points.

Slurry in the evaporator feed tank is pumped continuously to the first stage (fourth effect) where a constant fluid level is maintained. Each stage has a transfer pump and control system.

In order to recover heat energy from the hot recycle oil and from the fourth stage dry recycle slurry at about 125°C (255°F), three heat exchangers (HEX) are included, as shown in Figure 9. As a result, temperature of the recycle solids-oil slurry is reduced from about 125°C to 60°C (255°F to 145°F), thereby, increasing the temperature of sludge/oil slurry being transferred between stages.

It has been assumed that Isopar-L, an aliphatic light oil, would be used as the fluidizing medium. At one atmosphere pressure, the oil boils at 190°C to 205°C (375 to 400°F), decreasing to about 115°C to 125°C (240 to 260°F) at 0.10 atmospheres. The boiling point is considerably greater than that of water at all pressures which reduces the amount of oil vaporized along with water in the vapor chambers. However, the boiling point is sufficiently low that hydroextraction and steam stripping of Isopar is possible using steam of moderate temperature and pressure; therefore, dry solids can be produced which contain only small amounts of the original fluidizing oil. An Isopar and steam mixture is azeotropic in that the mixture has a lower boiling point than either individual component. This is of some help in the hydroextraction and steam stripping operation. Since Isopar is a non-polar fluid it will tend to dissolve grease, fats and oils, and other non-polar materials contained in the sludge. Isopar can be steam stripped from most of these dissolved oils leaving a residue, hereinafter referred to as "heavy oil" which can be used as a fuel.

A review of operating C-G installations indicates that there are numerous oils suitable for use as fluidizing media. Tallow, lubricating grade oil, and soybean oil are typical of oils presently in use. Isopar-L, which has been demonstrated as suitable for use with municipal sludge as well as other sludges, has become closely associated with the C-G process in recent years. Isopar-L was used successfully during pilot testing conducted as part of the LA/OMA Project. It vaporizes at 376 to 400°F at atmospheric pressure, and has a boiling point and consistency of quality that makes it highly desirable for use with the C-G process, particularly when hydroextraction

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is included. The popularity of Isopar-L, however, is due to the interest in marketing C-G products such as animal feed from the Coors facility. In those applications, the purity of Isopar-L is very desirable. For C-G applications, such as that proposed for the Los Angeles HERS project, any light oil with characteristics similar to Isopar-L is suitable. The characteristics of Isopar-L and similar light oils are shown in Table 6.

Table 6. SUITABLE LIGHT OILS FOR C-G PROCESS

Property	Isopar-L	Amsco 160	Chevron 410B
Distillation, ASTM D-86, °F			
IBP	370	367	368
10 percent	376	372	378
50 percent	382	376	387
90 percent	393	389	402
EP	405	410	417
Flash point, ASTM D-56, °F	144	142	142
Specific gravity at 60°F	0.767	0.7945	0.8034
Viscosity, centipoise at 100°F[a]	1.1	1.3	1.3
Cost, $/gal[b]	1.59	1.38	1.72

[a] Viscosity based on estimates by Foster Wheeler Energy Corporation
[b] Prices are for comparison purposes only.

In most multi-effect systems, it is desirable to evaporate about equal quantities of water in each stage. However, heat recovery requirements often dictate varying water evaporation rates for different stages. In the case of the hydroextraction steam stripping technique, approximately equal quantities of water are evaporated in the first three stages and a lesser amount in the fourth stage whereas for the vacuum stripping and distillation, a more equal evaporation results in all four stages.

Condensate collected from the first two evaporation stages will contain distilled fluidizing oil in amounts up to about 40 percent or higher by weight. Vapor from the fourth stage will contain distilled oil in amounts up to about 100-150 percent of

the water evaporated depending on the temperature of the slurry in the fourth stage.

In a single effect evaporator operating at 72°C (162°F), the partial pressure of water and Isopar is about 34,500 Pa (5 psia) and 4,140 Pa (0.60 psia), respectively. Since the moles of gas are proportional to the vapor pressure, the mole percentage of water to Isopar in the vapor would be about 8.3 to 1. However, actual weight percentage would be about 0.88 to 1 of water to Isopar. Even through the partial pressure of Isopar is significantly lower than water, the higher molecular weight results in a large weight percentage being evaporated in each effect.

The water-oil condensate is decanted in small gravity separation tanks and the oil is returned automatically to the stage from which it has been evaporated. An interface controller maintains a suitable oil level in each of these decantation tanks. Water is discharged to a larger oil-water separation tank where a more thorough separation of remaining oil from water is made. Since this water has been heated during the evaporation step, recovery of the heat is made by flashing to the higher vacuum of the preceeding stage. Two such flash units are employed in a four effect evaporator system. Trace quantities of oil remaining in the condensate are removed in a coalescer leaving a high quality water.

A portion of the dry sludge-oil slurry (about one half) is recycled back though the heat exchangers to the fluidizing tank and the balance is centrifuged to produce dry solids containing about 40 percent oil. It is important to note that the dry sludge-oil slurry also contains the "heavy oil" which is approximately equal to 10 percent of the digested primary sludge feed (dry weight basis).

A portion of the recycled oil, approximately 25 percent, is pumped to the Heavy Oil Separation Still where 80 percent of the heavy oil is recovered. The balance of the oil is returned through heat exchangers to the fluidizing tank. Residual quantities of light oil leaving the Separation Still with the heavy oil are recovered through a vacuum stripper unit and the heavy oil is discharged from this unit. Heavy oil may be filtered depending on the proposed use and is thought to be suitable for use as a fuel oil. However, oil will not be filtered in the HERS design since it will be fired in a fluidized bed incinerator.

If the heavy oil is not separated from the recycled Isopar the Isopar-heavy oil mixture would reach a saturation level. The heavy oil will then eventually show up in the centrifuged solids. Since only the Isopar, being a light oil, is distilled

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off in the hydroextraction process, heavier oils would tend to stay with the dried sludge. If dried sludge is to be thermally processed for energy recovery, heavy oil may not need to be separated from the sludge, and steam required to operate the C-G process could be supplied from the thermal processing system. In fact, keeping the heavy oils in the sludge is an advantage if the product is thermally processed. If separated, the heavy oil would have to be remixed with the solids or introduced separately into the pyrolysis unit.

If energy recovery is not a part of the sludge handling scheme, then separation of the heavy oil becomes more important. The heavy oil could supplement the fuel requirement for the boiler operation which supplies steam to the C-G process in the latter case.

Centrifuged solids, containing light fluidizing oil and other dissolved heavy oil, are conveyed to a "Hydroextractor". The hydroextractor is a type of indirect steam dryer. Heat is supplied to the hydroextractor contents by indirect heat exchange with steam. Steam is also directly sparged through the product to steam distill the Isopar at a temperature of about 120°C to 160°C (250°F to 325°F) at atmospheric pressure. An alternate technique is to distill the Isopar without any direct steam input at a vacuum of 0.5 atmospheres. Energy required to raise the temperature of the product to 160°C (325°F) and provide the heat of vaporizaticn of the oil is obtained by supplying steam to the internal hollow mixing conveyor flights and the steam jacket of the hydroextractor unit. Vapors of the hydroextraction unit enter the Heavy Oil Separation Still to separate the oil fractions. Isopar and steam are then returned to the fourth stage vapor chamber to recover the heat value.

Dry product is withdrawn from the system after hydroextraction. Process condensate is recycled back to the treatment plant. All vent gases after condensation for oil recovery are combusted in the boiler or thermal reactor.

Design Criteria (Reference 2)

General design criteria are listed in Table 7. The number of effects and the required evaporation efficiency depend on the situation. A two-effect system may be most economical in some cases. Also, redundancy or reliability requirements are site specific. The Los Angeles design incorporates three modules, each capable of handling 50 percent of the average design load. This level of redundancy is dictated by the large quantity of sludge being processed, the lack of alternative disposal options in emergency situations, the need to handle peak sludge production rates, and estimated downtime for routine maintenance. The City of Trenton, however, will use a

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single process train, sized for above-average production rates and designed to operate five days/week. Finally, Isopar will probably be used as fluidizing oil only where a food grade product is to be produced. Other petroleum based oils are more readily available and less expensive.

TABLE 7. CARVER-GREENFIELD DEHYDRATION DESIGN CRITERIA

Item	Criteria
Number of Effects	2, 3 or 4
Evaporation Rate	2.3 kg water/kg steam
Steam Characteristics	448,200 Pa (65 psia) saturated
Boiler Efficiency	75%
Fuel Value of Extracted Heavy Oil	41,850 kj/kg (18,000 Btu/lb)
Fluidizing Oil	Isopar-L
Fluidizing Oil Make-Up	1% by weight of dry solids fed (assumes hydroextraction is employed for oil recovery)
Weight of Isopar-L	766 kg/cu m (6.388 lbs/gal)
Outfeed	95% solids

Figure 10 shows the four-effect system employing the hydroextraction process recommended for the Hyperion Energy Recovery System (HERS) project. The system downstream of wet cake storage but including the use of digester gas consists of the following major components (Reference 11):

- C-G dehydration system
- Fluidized bed boiler system
- Fluidized bed air emission control system
- Digester gas cleanup system
- Combined cycle power plant

FIGURE 10. Schematic Flow Diagram, HERS Carver–Greenfield Process.

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The dried sludge product from the C-G process in the HERS projects will be thermally processed for energy recovery. The thermal process system selected after a Phase I study resulted in the use of a fluidized bed reactor (Reference 13).

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ENERGY ANALYSIS - REQUIREMENTS AND RECOVERY POTENTIAL (Reference 2)

A mass and energy balance for combined C-G drying and thermal processing is shown in Figure 11 based on the HERS project design.

In developing the mass and energy balance it was assumed that any extracted heavy oil from the C-G process is combined with dry product solids and pyrolyzed in a multiple hearth furnace (MHF). Low energy fuel gas produced under partial oxidation conditions in the multiple hearth would be immediately afterburned and passed through a boiler for steam production. The mass flow and temperature of flue gases exiting the afterburner were calculated from a heat and mass balance considering the caloric content of the feed and 140 percent stoichiometric air supply. Steam production was calculated assuming an exit gas temperature from the boiler of 204°C (400°F). Electrical production will include a condensing steam turbine with an extraction of process steam for the C-G unit at 1140 KPa (165 psia). Higher steam pressures are used in the HERS design than indicated in Table 7 due to the use of electrical production turbine exhaust steam.

About 38 percent of the steam produced is required for operation of the C-G process with the remainder available for production of electricity. About 6,260 KW of the total 7580 KW produced results from steam condensed at 22,100 Pa (3.2 psia). The remainder is derived from that portion of input steam extracted at 1140 KPa (165 psia). If vacuum hydroextraction is used, only about 22 percent of the process steam would be required at 1,140 KPa (165 psia) with the remainder at 550 KPa (80 psia). If two extractions were made from the turbine, one each at 550 and 1,140 KPa (80 and 165 psia), electrical production could be increased to about 8,019 KW, approximately a 6 percent increase. It should be noted that other steam turbine configurations are possible; for example, a condensing turbine with a separate backpressure turbine for steam used in the C-G. However, electrical production would not differ significantly. Therefore, the system shown in Figure 11 represents the potential energy budget for a combined process of dehydration and thermal processing using a proven energy conversion system.

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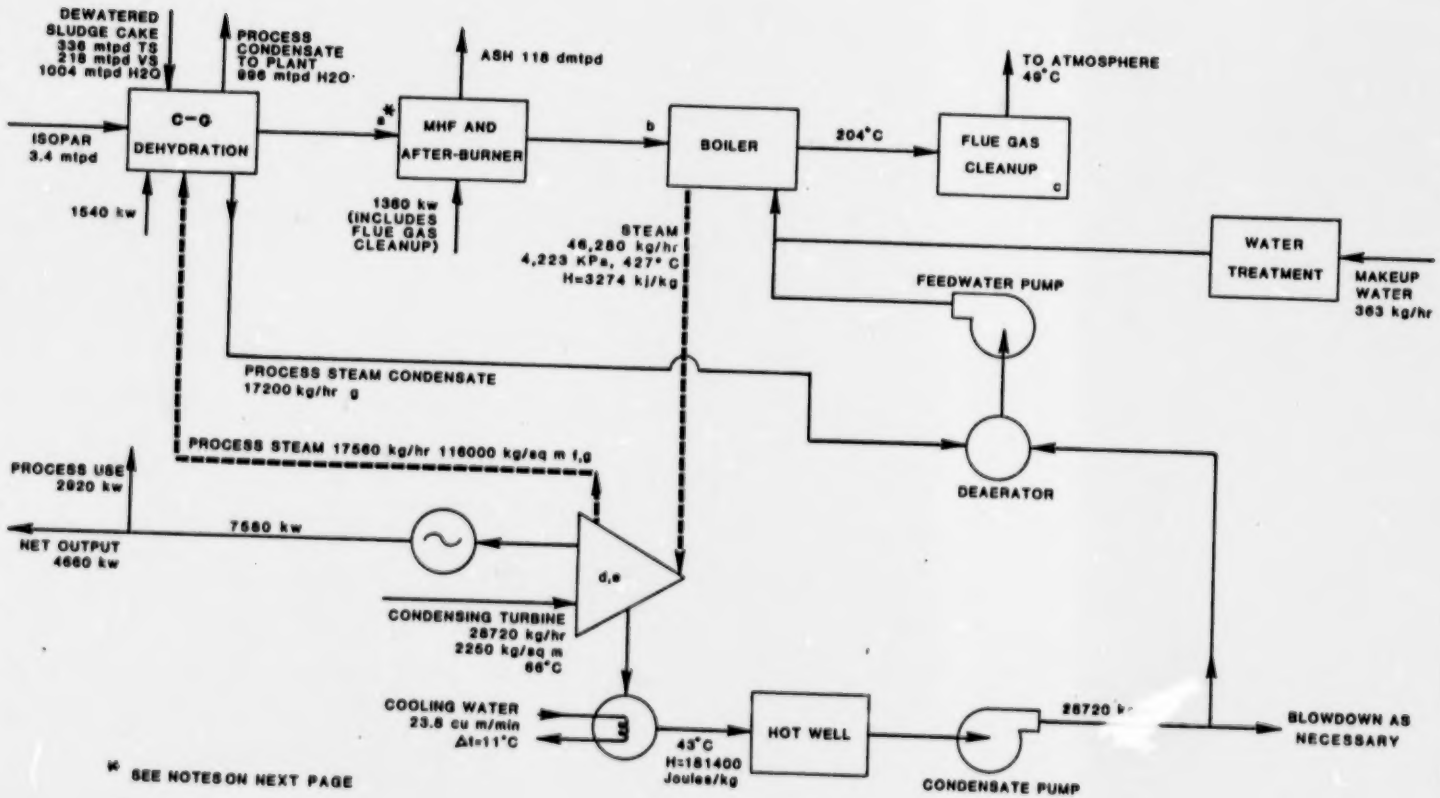

FIGURE 11. Carver-Greenfield Thermal Processing System Mass and Energy Balance (Reference 1).

Figure 11 continued

NOTES

a. Feed to MHF contains 197 dmtpd (217 dtpd) of VS @ 21.1×10^3 kJ/kg (9100 BTU/lb VS) combined with 21 mtpd (23 tpd) of extracted heavy oil @ 41.9×10^3 kJ/kg (18,000 Btu/lb) and 16 mtpd (18 tpd) of residual water.

b. Mass flow and temperature calculated from heat balance assuming 140 percent stoichiometric air in MHF and afterburner combined. Flue gas temperature is greater than 1538°C (2800°F) in this example.

c. High energy venturi scrubber and multiple tray scrubber assumed.

d. Steam turbine electrical production at 4.6 kg/hr (10.1 lb/hr) per KW extracted @ 22 KPa (3.2 psia) and 13.3 kg/hr (29.4 lb/hr) per KW extracted @ 1,135 KPa (165 psia).

e. Separate backpressure turbine could also be used.

f. With vacuum applied to hydroextraction unit, about 22 percent of steam requirement would be at 116,000 kgs/sq meter (165 psia) with remainder at 56,250 kgs/sq meter (80 psia). Two extractions from turbine at those pressures would be possible with some increase in electrical conversion efficiency.

g. Assumes 5 percent consumptive loss of steam in vacuum hydroextraction and Isopar distillation system. If hydroextraction conducted at one atmosphere, consumptive loss could increase to 65 percent of applied steam. Heat value of this direct steam is recovered in the process in either case.

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OPERATION AND MAINTENANCE REQUIREMENTS (Reference 2)

Table 8 lists the labor, power and chemical requirements for the C-G process only based on the City of Los Angeles proposed full-scale Hyperion Energy Recovery System (HERS) (Reference 11). The design data for HERS is presented in the cost section.

TABLE 8. OPERATION AND MAINTENANCE REQUIREMENTS

Design	265 dtpd[a] @ 20 percent solids
Labor	10 personnel @ 1500 hrs/yr each
Power used	1900 kWh/day
Chemical requirements (carrier oil)	1,200 kg/day or 766 kg/cu m (2,650 lb/day or 415 gal/day @ 6.388 lb/gal)[b]

[a] dry tons per day
[b] based on total oil loss of 0.5 percent of output of dry solids

The process is quite flexible in terms of variations during operation. The heart of the process is the multiple-effect evaporator train, which consists of feed and circulation pumps, heat exchanger, vapor chamber and connection piping. As such, the system is comprised of mostly duplicative equipment which is non-proprietary and available from more than one manufacturer. These equipment sections (e.g. an evaporative effect unit) are amenable to duplication or by-pass arrangement to assure 100 percent reliability. Thus, an extra evaporative effect (pumps, heat exchanger, vapor chamber) may be piped in parallel with the ones in normal operation to provide switch-over capability in case one of the effects is shut down temporarily for any reason. A way to assure reliability without extra equipment is to have bypass arrangement such that a normal 4-effect system can be operated as a 3-effect system by using slightly more process steam and higher temperature drop across the system with attendant decrease in efficiency. With these and certain other essential spare equipment, the Carver-Greenfield system can cope with upset conditions without having 100 percent redundancy.

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The C-G process poses no special maintenance problems. The maintenance effort required in the dry materials phase and distillate condensing operations will be greater than in other process segments. All required maintenance procedures are within the capabilities of well trained municipal personnel. Equipment durability and reliability are quite good. The employment of proper preventive maintenance procedures for the C-G process can be expected to result in smooth running operations with long life.

COST

Cost estimating procedures follow the US EPA's cost-effectiveness guidelines. Cost-effectiveness is defined to include monetary cost and environmental and social impact assessment. Capital cost estimates are based on the Engineering News Record Construction Cost Index (ENR CCI) 20 cities average for March 1981 or 3384. Capital costs are based on an operable system with a 20-year life. If a system has an expected service life of less than 20 years, the capital cost includes the present worth of subsequent replacement at current values, required to obtain a 20-year service life. Salvage value for estimated service life beyond 20 years is not considered.

Capital costs include construction, engineering, legal, administration and contingencies for all building, equipment and labor, energy, chemicals and routine replacement of parts and equipment (when replacement is required at intervals of five years or less). Equipment cost estimates were based on preliminary layouts and sizing, and were obtained from the City of Los Angeles proposed full-scale system (Reference 11).

Basic cost assumptions include:

Service life	
Equipment	= 20 years
Structures	= 40 years
Interest rate (EPA required)	= 7 percent
Non-component costs	= Piping @ 10% Electrical @ 8% Instrumentation @ 5% Site preparation @ 5% Total = 28% of construction cost
Non-construction cost	= Engineering and construction supervision @ 15%

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	Contingencies @ 15% Total = 30% of construction and non-component costs
Capital cost	= Construction cost plus non-component and non-construction costs
Capital recovery factor	= 20 years, 0.09439 40 years, 0.07501
Present worth factor	= 20 years, 10.594 40 years, 13.332
ENR CCI (20 cities average for March 1981)	= 3384
Labor Cost (March 1981)	= $15/hour
Energy cost (March 1981)	
Electricity (industrial rate)	= $0.014/MJ ($0.05/kilowatt-hour)
Gasoline	= $0.396/liter ($1.50/gallon)
Natural Gas	= 0.053/cu m ($1.491/1,000 cu ft)

Three parallel, four-effect C-G process trains were assumed. Each process train would be a complete system designed to handle 50 percent of the sludge loading. This would provide 50 percent standby for all equipment based on the proposed sludge loading rate.

A four effect C-G system is proposed for the HERS system including the following subsystems:

- Sludge cake fluidizing
- First stage de-oiling by centrifuge
- Second stage de-oiling by hydroextraction
- Light/heavy oil separation
- Sewage oil recovery

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- Condensate polishing
- Once-through cooling of condensate using secondary treated effluent
- Dry product storage
- Pelletizing system
- Oil storage

Table 9 presents the preliminary design criteria for this system and Table 10 presents the cost breakdown. It should be noted that, at the time of this writing, these cost estimates were still in the draft stage and are subject to revision. Non-component costs are included in the equipment cost estimates.

Process license fees are included in the cost estimate. The license fees of approximately $1.4 million is based on a formula that accounts for energy savings. The license fee formula varies from project to project depending upon several factors including energy savings. For example, the license fee at Trenton, New Jersey was approximately $0.82 million without an allowance for energy savings.

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TABLE 9. PRELIMINARY DESIGN CRITERIA FOR CARVER-GREENFIELD SYSTEM, HYPERION ENERGY RECOVERY SYSTEM, CITY OF LOS ANGELES, CALIFORNIA (Reference 11)

Item	Preliminary Design Criteria
Number of modules	3
Sludge capacity, tons dry solids/day	135 (each)
Evaporative capacity, lb/hr	63,750 (each)
Oil fluidizing subsystem	
Makeup oil tank	
Number	2
Diameter, ft	12
Height, ft	30
Materials of construction	Carbon steel
Fluidizing tank	
Number	3
Diameter, ft	8
Height, ft	9
Tank mixer type	Twin turbine with stabilizers
Materials of construction	304-SS
Sludge grinder	
Number	3
Materials of construction	Carbon steel
Evaporation subsystem	
Vapor drums	
1st stage	
Number	3
Diameter, ft	6.8
Height (including 60° hopper), ft	29
2nd stage	
Number	3
Diameter, ft	5.3
Height (including 60° hopper), ft	26.5
3rd stage	
Number	3
Diameter, ft	4.6
Height (including 60° hopper), ft	24
4th stage	
Number	3
Diameter, ft	4.6
Height (including 60° hopper), ft	24
Materials of construction (all)	Carbon steel

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Table 9 (continued)

Item	Preliminary Design Criteria
1st stage condenser	
Number	3
Type	Forced feed circulation, single pass
Tube length, ft	40
Shell diameter, in.	28
Number of tubes	365
Heat exchanger area, sq ft	3,560
Materials of construction	304L-SS tubes and heads; carbon steel shell
1st to 4th stage heat exchangers	
Number (each stage)	3
Type	Forced feed circulation
Tube length, ft	20
Shell diameter, in.	45
Number of tubes	720
Heat exchanger area, sq ft	3500
Materials of construction	304L-SS tubes and heads; carbon steel shell
De-oiling and oil separation subsystem	
3rd and 4th stage settling tanks	
Number (each stage)	3
Diameter, ft	9
Height (including 45° hopper), ft	22
Materials of construction	Carbon steel
Centrifuge	
Number	3
Type	Horizontal, solid bowl
Materials of construction	Carbon steel, 304-SS conveyor
Light oil evaporator	
Number	3
Materials of construction	316L-SS, tubes; carbon steel, shell
Hydroextractor	
Number	3
Diameter, ft	4
Length, ft	24
Materials of construction	316 SS clad
Recovered light oil storage tank	
Number	2
Storage, days	3
Materials of construction	Carbon steel

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Table 9 (continued)

Item	Preliminary Design Criteria
Sludge oil storage tank	
Number	2
Storage, days	3
Materials of construction	Carbon steel
Pelletizer	
Number	3
Rate, tons/day	132.5
Minimum densification factor	2:1
Materials of construction	Carbon steel
Pellet storage tanks	
Number	3
Storage, days	
Pellets	6
Powder	3
Materials of construction	Carbon steel
Standby boiler	
Number of units	1
Type	Firetube, gas fired
Pressure, psig	150
Capacity, lb/m	50,000

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TABLE 10. ESTIMATED COSTS FOR LOS ANGELES CARVER-GREENFIELD PROCESS (Reference 11)

Capital Cost ($) (installed for 265 dry tons/day)	
Equipment (non-component costs included)	
Tanks and vessels	$1,199,000
Drums	564,000
Heat exchangers and condensers	2,302,000
Pumps	2,011,000
Compressors	249,000
Centrifuges	995,000
Grinders	191,000
Fluidizer tanks	162,000
Hydroextractors	829,000
Towers and stills	402,000
Oil-water separator	228,000
Pelletizers	402,000
Dust collectors	46,000
Standby boiler	635,000
Piping systems and platforms	2,638,000
Instrumentation	958,000
Conveyors	129,000
Subtotal	$13,940,000
Engineering, legal, administration and contingencies, @ 30%	4,182,000
Process License Fee	1,400,000
Subtotal for equipment	19,522,000
Structures	3,459,000
Engineering, legal, administrative and contingencies, @ 30%	1,038,000
Subtotal for structures	4,497,000
Total Capital Costs	$24,019,000

continued

TABLE 10 (continued)

Annual Capital Cost ($/year)[a]	
Equipment	$ 1,843,000
Structures	337,000
Subtotal	2,180,000
O&M Cost ($/year)	
Labor[b]	$ 225,000
Power[c]	832,000
Chemicals[d]	167,000
Maintenance materials[e]	362,000
Subtotal	1,586,000
Annual Cost	$ 3,766,000
$/dry ton	$ 39

[a]Annual capital costs based on 7% interest, 20-year life for equipment, 40-year life for structures
[b]Labor cost based on 10 positions at 1,500 hours per year and $15 per hour
[c]Power cost based on $0.05/kW
[d]Chemical cost based on carrier oil cost of $0.381 kg ($0.173/lb) with losses of 0.5% in dried product
[e]Annual maintenance cost estimated at 2% of equipment cost

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SECTION 6

COMPARISON WITH EQUIVALENT CONVENTIONAL TECHNOLOGY

COST COMPARISON

The C-G process is a uniquely designed dehydration (drying) process. Other heat drying processes include:

- Flash dryers
- Spray dryers
- Rotary dryers
- Multiple hearth dryers
- Indirect steam dryers
- Sonic dryer

Indirect contact steam dryers as manufactured by Bethlehem or Bepex are the closest conventional technology to the C-G process since they are indirectly heated. The LA/OMA Project conducted an analysis comparing indirect steam dryers with C-G technology. The following conclusions were drawn from the comparison between steam drying and dehydration:

- Capital cost of both processes are comparable.
- Steam drying consumes significantly more energy which results in significantly higher O&M costs.
- Dehydration is less expensive than steam drying on an overall annual cost basis.

The available information on sludge drying equipment generally lacks key information necessary to develop accurate capital and O&M cost curves. Cost information on the flash, spray and rotary dryers is not readily available and data presented on multiple hearth dryers deal with the unit primarily as an incineration process rather than a drying process.

The LA/OMA Project obtained cost information from the manufacturers of rotary dryers. The information was based on an input of 1,525 wet metric tons per day (1,680 wet tpd) of sludge at 10 percent solids dried to 73 percent solid concentration. Table 11 presents the cost information for rotary dryers.

Operating costs have wide variations due to fluctuations in auxiliary fuel requirements for various feed material characteristics.

TABLE 11. EXAMPLE COST FOR ROTARY DRYER (Reference 11)

Input sludge cake	
Metric tons/day (wet)	1,525
Metric tons/day (dry)	152
% solids	10
Installed capital cost (@ ENR = 3384)	$6,198,000
Annual capital cost	585,000
O&M costs	
Labor	$ 450,000
Fuel	$4,525,000
Annual O&M costs	$4,975,000
Total annual cost	$5,560,000
$/dry metric ton	$ 100

Although the capital cost of rotary dryers is less than the C-G process, the significantly higher annual O&M cost as a result of higher energy requirements results in a lower annual cost for the C-G process ($40 to $60/dry metric ton). These results are generally correct when comparing the C-G process to conventional drying technology.

ENERGY

The overall evaporation energy requirement of the C-G process is less than that of comparable sludge drying processes as shown in Table 12.

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TABLE 12. ENERGY REQUIREMENTS (Reference 3)

Unit	Kj Input/Kg of Water Evaporated	Btu Input/lb of Water Evaporated
Spray dryer	4,650 minimum	2000 minimum
Flash dryer	5,120-6,280	2200-2700
Rotary dryer	5,580-6,510	2400-2800
C-G (4 effect)	810-1,050	350-450
Indirect steam	2,900	1,250
Other devices that use heat for drying and do not employ multiple effect evaporation	2,330 (plus heat lost due to inefficiencies of system)	1000 (plus heat lost due to inefficiencies of system)

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SECTION 7

NATIONAL IMPACT ASSESSMENT

MARKET POTENTIAL

The cost-effective and energy efficient dewatering/drying of residual wastewater solids prior to disposal or use is a major problem facing most municipal wastewater agencies nationwide.

Existing mechanical dewatering methods in widespread use (vacuum filtration, centrifugation, belt filters and filter presses) are expensive and performance is limited by the physical/chemical characteristics of residual solids. Heat treatment (e.g. wet oxidation) and heat drying processes present unique problems (e.g. odor, sidestream treatment, energy efficiency). Air drying processes are available for small plants but, because of land area requirements, are generally not suitable for large municipalities.

The C-G process apparently does not have the negative characteristics of existing dewatering/drying technology, is cost-effective and is energy efficient. Because of the nationwide need of small and large agencies for a more effective and efficient wastewater residual solids dewatering/drying process and because the C-G process is modular in design and adaptable to municipal wastewater facilities of 10 mgd capacity and greater, it appears that the nationwide market potential is significant.

Risk factors that currently limit the market potential include:

- Limited experience with wastewater residual solids. Although the C-G process has a successful history in the food processing and other industries, full scale experience with municipal wastewater residual solids is limited to two facilities in Japan. There are no full-scale operating facilities currently processing municipal wastewater solids in the U.S. The Los Angeles HERS project is the first full-scale design in the U.S.

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- The C-G process is mechanically complex. History of the wastewater treatment industry indicates that mechanically complex processes are a source of major operating and maintenance problems. However, the limited experience with the C-G process in the wastewater industry to date indicates that operation and maintenance problems are within the capabilities of municipal wastewater agencies.

Foster-Wheeler Corporation markets the C-G system in the U.S. and can also act as the designer. However others are not precluded from designing the system as long as a license fee is negotiated directly with Dehydrotech. For example, the City of Los Angeles license fee has been negotiated directly with Hydrotech without Foster-Wheeler involvement.

There is no sole source equipment or appurtenant hardware in the C-G system. In the Los Angeles design, Foster-Wheeler developed plans and specifications for the C-G equipment while other consulting engineers prepared the overall system design. The construction will be competitively bid by general contractors which is normal municipal practice.

COST AND ENERGY IMPACTS

It appears that the cost and energy impacts on a national level would not be significant but could be significant for a local agency/municipality. In addition to annual cost and energy savings for solids dewatering/drying, there would be significant cost and energy savings associated with the transport and disposal or use of the residual solids because of the dryness and, therefore, reduced volume.

In making cost and energy comparisons with other mechanical, chemical, heat, and air drying methods, it is important to compare the processes on a wet weight/volume basis as well as a dry weight/volume basis. The end product wetness and volume varies with each process and determines the final cost of disposal or use. Likewise, site specific comparisons for decision-making should be made on a total system basis (e.g. dewatering, drying, disposal/use) rather than a unit process basis.

The C-G process is generally cost-effective in modules to service a range of treatment plant capacity from about 10 mgd to over 300 mgd. Although the process has been used on a pilot scale of 1 mgd capacity or less, it is generally not cost-effective at less than 10 mgd wastewater plant capacity.

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